BEP

Lloyd's Register Technical Association

A GUIDE TO PUMPING AND PIPING ARRANGEMENTS

J. Crawford

Paper No. 1. Session 1978-79

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

OM/FL/2

INTER-OFFICE MEMORANDUM

LLOYD'S REGISTER OF SHIPPING FOUNDED 1760

From Headquarters London

To Hong Kong

Our Ref. TSG/M/453/44161/SS

Your Ref. BEP/ml/007/PA81

Subject Piping Systems

Date 29th October 1981

1. We refer to your memorandum dated the 22nd October 1981 concerning the above.

2. For all types of ships Section 10 of Part 5, Chapter 13, should be complied with and drainage arrangements for propelled ships should comply with Section 1 to 8 as applicable.

3. Any proposal to dispense with drainage arrangements and air and sounding pipes would require to be specially approved.

Philip Uttan.

for the Secretary

PAU/cdt

Received -4 NOV 1981
For BEP.
Answered
File

Hon. Sec. D. T. Boltwood
71, Fenchurch Street, London, EC3M 4BS

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SKETCH INDEX

A GUIDE TO PUMPING AND PIPING ARRANGEMENTS

By J. CRAWFORD

1 INTRODUCTION

It is now some years since the last paper on this subject was given by Mr. H. R. Clayton (1960) and having regard to the variety of ships now being dealt with it is thought a further paper on this subject may serve a useful purpose. Many of the piping arrangements, as outlined in Mr. Clayton's paper, are still being fitted in ships today. That is to say the basic requirements have not really altered, only the application, in view of the complexity of the systems now being used. Further, the Rules have now been rewritten and rearranged and the 1978 issue has the new format. Unless stated otherwise all the Chapters referred to in this paper are contained in Part 5 of the Society's 1978 Rules.

2 PLANS

It is necessary to first make a few general comments on the subject of pumping and piping plans.

It has become the usual practice for the plans to be submitted in diagrammatic form, and this is now a Rule requirement in so far as piping arrangements are concerned.

The advantages of presenting pipe arrangements in diagrammatic form are shared by all concerned. The builders have basic plans from which the scale plans can be built up and, being smaller, they are less expensive, bearing in mind that three copies have to be forwarded for approval. The Surveyor has plans of reasonable size which he can use for reference on the ship when checking the arrangements. Finally, such plans are more conveniently and quickly dealt with in the Head Office and eventually take less storage space in the Records Department when the ship is completed, which is not an unimportant point in view of the pressure on available space.

Many firms adopt the method of having a separate diagram for each of the piping systems in the machinery space, which simplifies the work and reduces the possibility of mistakes. The systems usually dealt with in this way are as follows:—

Bilge	Lubricating oil
Ballast	Compressed air
Fuel oil transfer	Steam
Fuel oil service	Exhaust
Cooling water	Feed

Other firms combine two, or perhaps three, diagrams on one plan, but the first method is to be preferred.

Plans come in from every class of ship and engine builder, both at home and abroad, and generally the diagrammatic work is good. There are, nevertheless, a few points which may be mentioned with a view to their improvement.

A fairly common mistake is to endeavour to show, in diagrammatic form, the intended position of pipes in a ship. This means that where, at a restricted point, some pipes have to lie one above another, they will be represented in the diagram by a single line, and it may be difficult for an observer to follow the pipe diagram correctly. To prevent any possibility of error all pipes in a vertical plane should be shown diagrammatically lying side by side.

Another point which should be stressed is the importance of making quite clear whether lines which cross each other represent pipes which are entirely separate or form a pipe junction. Figure 1 shows our methods, which are in general use.

Method A is not recommended because it frequently happens that the little marks signifying the flanges are inadvertently omitted, with the result that pipes which are intended to be shown connected appear to cross each other, throwing the scheme into confusion. Method B is better but apparently the break in a line which signifies a cross-over is sometimes overlooked when the plan is traced, with a similar result to that mentioned for Method A. Method C is considered to be the most reliable and is at present probably the most used.

Method D is that recommended in BS MA 1 Part 1 1969, 'Graphical Symbols Representing Pipe Lines in Ships', and this method would now appear to be gaining favour.

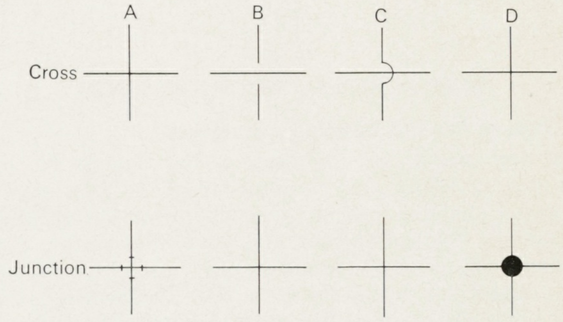


Fig. 1

Piping Symbols

Whilst on the subject of pipe lines, it must be emphasized how necessary it is that the sizes of the pipes are clearly marked. It is essential to know the bore of the pipe and this should be clearly stated on the plan. The outside diameter or the thickness of the pipe should also be stated for pressure pipes, and for air and sounding pipes which are fitted to tanks forming part of the ship's structure. Reference should be made to Chapter 12 Table 12.2.4 for minimum thickness of pipes.

The direction of flow should also be indicated on pipes leading to and from pumps, and each pipe should be completed to the final terminal point. It is not uncommon for a pipe to be shown branching out of a main line and then discontinued without any explanation as to its purpose or function.

Diagrams of the bilge system in the machinery space should always indicate the capacity of the pumps for bilge service and, even though it is a Rule requirement that this information be furnished, this essential information is often omitted. Failure to comply with this leads to much unnecessary correspondence.

Symbols are most helpful in diagrammatic work but their usefulness can be greatly over-estimated. Some firms have a table of standard symbols amounting to 100 or more, and it is exceedingly difficult to keep their meaning in mind without constant reference to the table. It is advisable to keep the number of symbols within reasonable limits and they should be indicated in some convenient position on each plan. In the

case of machinery space piping diagrams the following fittings can be suitably represented by symbols:—

- Screw lift valve
- Gate valve
- Butterfly valve
- Ball valve
- Screw-down non-return valve
- Non-return valve without spindle
- 'L' or 'T' ported cock
- Open bottom cock
- Self-closing cock or valve
- Deck controlled valve
- Relief valve
- Reducing valve
- Filter or strainer
- Mud-box with straight tail pipe
- Strumbox
- Sight glass or alarm

No attempt will be made to suggest a code of symbols as most firms have their own ideas on the subject and these tend to vary widely.

3 SHIP PUMPING ARRANGEMENTS

3.1 Plan of General Pumping Arrangement

The first plan to be considered is the General Pumping Arrangement, which may be regarded as the basic plan for any ship's pumping system. In most shipyards this plan is prepared by the shipbuilders and shows the suction pipes, together with the air and sounding pipes, for all the compartments outside the machinery space. The Continental practice often divides the plan into two parts: one part prepared by the engine drawing office shows all suction pipes both inside and outside the machinery space, whilst the other, which is the responsibility of the ship drawing office, shows the air and sounding pipes.

Figure 2 shows a typical example of this plan for a cargo ship of about 138 m in length, and for the purpose of illustration, the plan is described in detail. In order to deal with the plan systematically, and to have a permanent record of the case, a calculation sheet is used, Figure 3. It is usually necessary to refer to the principal structural plans to obtain the dimensions of the ship and also details of the frame spacing, in order that the compartment lengths may be calculated. Care must be taken to allow for any change in the frame spacing which may occur in the compartments. It is advisable to check that the sum of the compartment lengths agrees approximately with the length of the ship.

3.2 Bilge Suctions

The Rule sizes of the bilge suctions for the machinery space and the holds are determined and compared with the proposed sizes of the suctions in these compartments. Unless otherwise stated, it is assumed that the sizes shown on the plan indicate the bore of the pipe.

Provision should be made for the drainage of all dry spaces which cannot drain to the bilge suctions fitted in the main compartments. Cofferdams, duct keels and tunnels, if fitted, should be provided with bilge suctions led to the main bilge line. The forepeak store spaces and chain locker may be drained by hand pumps. The steering gear compartment and other enclosed spaces above the aft peak tank may be drained by hand or power pump suctions, or by means of scuppers led to the tunnel. All such scuppers must be fitted with self-closing cocks having parallel plugs.

If, however, the compartment above the aft peak extends below the light load water line, the suction should be led to the bilge main in the normal manner.

3.3 Tank Suction, Filling and Air Pipes

The next step is to complete the table of tank suctions, filling and air pipes shown on the calculation sheet. The suctions or air pipes may also be the filling pipes and this should be indicated in the manner shown in the table. Any tanks having connections to power pumps are required to have air pipes with a total cross-sectional area 25% in excess of that of the filling pipes.

Tanks in the category just mentioned are usually those arranged for the carriage of oil fuel or water ballast, and are capable of being pumped up by the ship's pumps or shore pumps. The exceptions are (a) tanks which can be filled only by means of a hose loosely inserted in the filling pipe on deck and (b) water ballast tanks which can only be 'run-up' from the sea.

Air pipe closing arrangements should, however, be of such a type as to prevent any excessive vacuum occurring during pumping out. Experience has shown that where large suctions are employed there is the possibility, especially in the case of air pipes incorporating ball floats, for the ball to be lifted due to the vacuum and effectively seal the air pipe with the possible result of damage to the tank structure.

If, in the case of double bottom tanks, the wing and centre suction and filling pipes are connected to the same valve chest, the size of the inlet branch to this chest may be the limiting factor for filling purposes. For example, a tank may have centre and wing suction and filling pipes, 125 mm and 100 mm bore respectively, led to a chest which has a 150 mm bore branch to the ballast main and/or the oil fuel main. Obviously, the size of the air pipe must be related to the size of this branch which has a cross-sectional area less than that of the combined area of the tank connections.

Again, some firms fit screw-down non-return (S.D.N.R.) valves on the wing suctions from double bottom tanks, in order that the tanks can only be filled through the centre suctions. The size of the air pipes should then be based on the size of the centre suctions.

Care should be taken to see that all air pipes are led to suitable positions above the bulkhead deck, and also that cofferdams, duct keels and void spaces in general are properly ventilated. It is considered that two air pipes should be fitted to such spaces to obtain a reasonable circulation of air. This point cannot be over-emphasized; a Surveyor lost his life through being asphyxiated after entering a forepeak compartment. The compartment was, apparently, a void space without adequate means of ventilation.

Attention is drawn to the Society's Safety Notice No. 2, dated 15th November 1976, with regard to Health and Safety at Work Act 1974.

3.4 Sounding Pipes

It should be ascertained that sounding pipes are fitted close to hold and tank suctions where practicable, and that they are led to accessible positions above the bulkhead deck. The only permitted exceptions are the short sounding pipes fitted in the machinery space. Short sounding pipes, where provided for tanks containing oil, should be fitted with self-closing cocks, having parallel plugs and be so arranged that they are readily accessible and do not terminate in locations where spillage could cause a possible hazard, Chapter 13, 10.13.2.

Short sounding pipes to tanks, other than oil fuel and lubricating oil tanks, are to be fitted with shut-off cocks/valves or screwed caps securely attached to the sounding pipes, Chapter 13, 10.13.3.

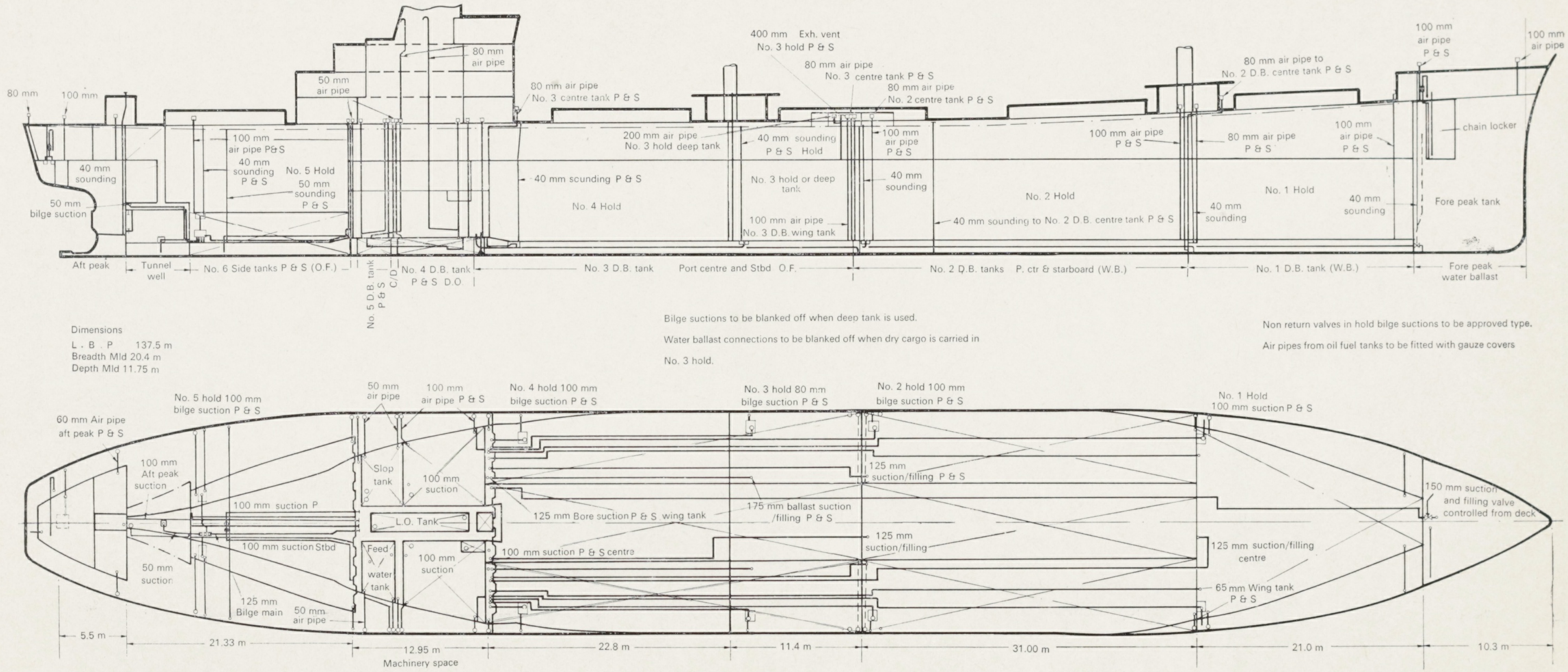


FIG. 2

General Pumping Arrangements

SHEET No. 10

PUMPING AND PIPING ARRANGEMENTS

SHIPBUILDERS:	YARD NO.
ENGINEERS:	ENGINE NO.
BOILER MAKERS:	BOILER PRESS
Owners:	FUEL OIL
CLASS CONTEMPLATED: 100A1	I.G. SYSTEM NO

Type of Vessel: General Cargo

Deep Tanks: Water or Dry Cargo

Dimensions: Length 137.5 m, Breadth 20.4 m, Depth 11.75 m

R.Q.D. (if any): Height , Length : Tonnage 9000

Position of Machinery: AFT OF AMIDSHIP

Type of Machinery: DIESEL No. of Screws 1

Power of Machinery (Total): I.H.P. , B.H.P. 7500, S.H.P.

Size of Cooling Water Inlet: 225

	RULE	PROPOSED	
Size of Bilge Injection	225	225	Stbd fwd
Size of Main Bilge Line $d_m = 1.68\sqrt{L(D+B)}+25$ mm $1.68\sqrt{137.5(20.4+11.75}+25 = 134.7$	135	150	
Size of Direct Bilge Suction	135	150	P. Aft
Size of Main Bilge Line in Tankers $d_1 = \sqrt{2\times d_2^2}$			
Size of Branch Bilge Suction $d_b = 2.15\sqrt{C(B+D)}+25$ mm $2.15\sqrt{129.5(20.4+11.75)}+25 = 68.8$	70.0	80	Sounding
Frame Spacing 0–9 @ 610, 9–146 @ 760, 146–170 @ 685, 170–187 @ 610 mm			

Compartment	Frames	Length		RULE	PROPOSED	
Machinery Space	37.54	12.95	$2.15\sqrt{12.95\times 32.15}+25$	70	80 F. P. & Stbd 80 A. P. & Stbd	
No. 1 Hold	140–170	21.03	$= 81.9$	80	100 P/S	40
No. 2 Hold	99–140	31.24	$= 94.2$	95	100 P/S	40
No. 3 Hold/DT	84–99	11.43	$= 67.26$	70	80 P/S	40
No. 4 Hold	54–84	22.86	$= 84.3$	85	100 P/S	40
No. 5 Hold	9–37	21.33	$= 82.3$	85	100 P/S 50 Aft	40
No. 6 Hold						
Peaks F.	170–187	10.37			150	40
A.	0–9	5.5			50/100	40
Total Length		**136.71**				

Rule Capacity of Power Pumps on Bilge Service $\frac{5.75}{10^3}$ $dm^2 = 110\ m^3/Hr$

No. & Capacity of „ „ „ „ „ $\left\{\begin{array}{l}\text{GS PUMP} = 120\ m^3/Hr \\ \text{BILGE PUMP} = 120\ m^3/Hr\end{array}\right.$

Are these Pumps of Self-Priming Type? YES

BALLAST PUMP = 400 m^3/Hr
OILY BILGE PUMP = 10 m^3/Hr

FIG. 3

Calculation Sheets

TANK		CONTENTS	SUCTION	FILLING	AIR & OVERFLOW		SOUNDING	REMARKS
Fore Peak		WB	150		100 F. 100 A. (P & S)		40	
No. 1 DB Tk		WB	60 W. 125 C.		100 F. P/S 80 A. P. & S.		40	
No. 2 DB Tk	P.	WB	125		100 F. & A.		40	
,,	C.	WB	125		80 F. P/S 80 A. P. & S.		40	
,,	S.	WB	125		100 F. & A.		40	
No. 3 Hold/DTk		Dry/WB	80 P/S/175		400 VENT 200 P/S		40	
No. 3 DBTk	P.	OF/WB	125		100 F. & A.		50	S.C.C.
,,	C.	OF	100 P. & S.		80 F. P/S 80 A. P/S		50	S.C.C.
,,	S.	OF/WB	125		100 F. & A.		50	S.C.C.
No. 4 DBTk	P.	DO	100		100 F. & A.		40	S.C.C.
,,	S.	DO	100		100 F. & A.		40	S.C.C.
Lub. Oil Tk		LO	80		80 F. & A.		40	S.C.C.
No. 5 DBTk	P.	SLOPS	50		50 F. & A.		40	S.C.C.
,,	S.	FEED WATER	50		50 F. & A.		40	
C/D		DRY	50		3 & 50		40	
No. 6 DB/DTk	P.	OF	100		100 F. & A.		50	
,,	S.	OF	100		100 F. & A.		50	
Aft Pk		WB	50/100		65 F. P. & S. 80 A.		40	
Eng. Rm Tks								
Diesel Oil Tk		DO		65	50	75	Sounding To be provided	
Diesel Oil Tk		DO		65	50	75		
H.O. Settling Tk		OF		75	50	90		
H.O. Service Tk		OF		75	50	90		
H.O. Service Tk		OF		75	50	90		
Overflow Tk		OF		90	90			
Boiler Oil Tk		OF		50	50	65	*See* Figure 19	

Sounding pipes from oil fuel and lubricating oil tanks, other than short sounding pipes described above, are to be led to safe positions on the open deck, Chapter 13, 10.12.1.

Sometimes it is not convenient to lead a sounding pipe through the top of a tank and an elbow type sounding pipe is proposed. However, an elbow type sounding pipe will always contain liquid to the same level as that in the tank, and in the event of the pipe being fractured, the contents of the tank would be discharged into the compartment in which the fractured pipe is situated. For this reason elbow type sounding pipes should either be led through a closed cofferdam or an adjacent tank containing a similar liquid.

The equivalent of an elbow sounding pipe is often proposed where the collision bulkhead is stepped, Figure 4. In order to obtain a straight run for the forepeak sounding pipe, it is often proposed to lead the sounding pipe through the cargo hold and into the tank at the step, with the result that, in the event of failure of the pipe through damage or corrosion where it emerges from the forepeak into the cargo hold, the contents of the upper part of the tank could be discharged into the cargo hold. A better arrangement is to lead the pipe through the tank with a slight curve so that it terminates, as near as possible, in the same position as the straight pipe. In the case of tugs and other small craft, it is sometimes an advantage to be able to sound a semi-deep tank from the machinery space. However, an elbow type sounding pipe is not acceptable, but a similar result can be obtained by leading a straight or slightly curved sounding pipe through the side of the tank at the top, Figure 5.

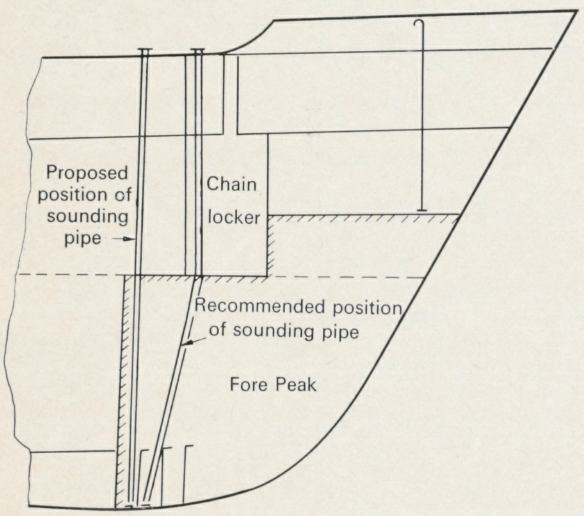


FIG. 4

Elbow Sounding Arrangements

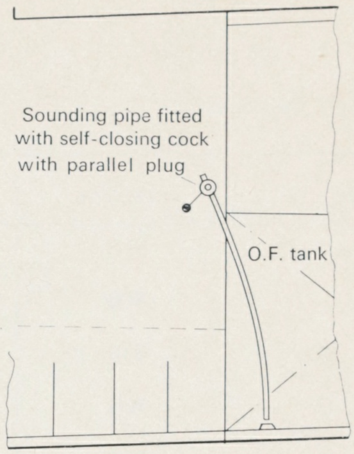


FIG. 5

Elbow Sounding Alternative Arrangement

At this stage the routine work on the general arrangement plan may be regarded as being completed, but it is possible that there will be other points to consider and the following notes may be useful in this respect.

3.5 Non-Return Valves on Hold Bilge Suctions

These valves are required by the Rules to be fitted at the open ends of bilge pipes in cargo holds where the pipes pass at some point in their length through a deep tank. In addition, they are often fitted at the owners' request or, in the case of a passenger ship, to comply with the Regulations of the International Convention for Safety of Life at Sea.

The Rules stipulate that such valves should be of an approved type which does not offer undue obstruction to the flow of water. Figure 6 shows two types which are acceptable and it will be appreciated that the aim in each case is to ensure that, as far as possible, the valve will not become choked with such foreign matter as may be found in bilges.

3.6 Scuppers for Draining Holds

Scuppers are sometimes proposed for draining holds into the machinery space or shaft tunnel on the basis that, if self-closing cocks are fitted, the requirements of Chapter 13, 3.7.1, regarding intactness of machinery space bulkheads and tunnel plating, are not infringed. Experience has shown, however, that self-closing cocks are often secured in the open position and for this reason cocks are not acceptable.

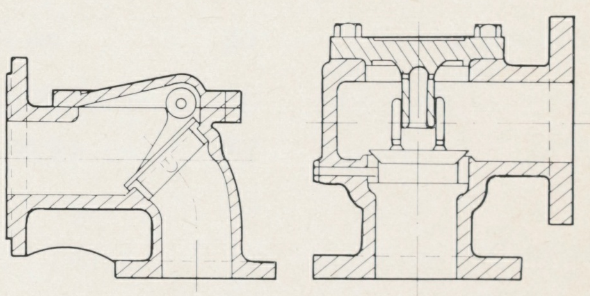


FIG. 6

Non-Return Valves

If scuppers are fitted they should be led to a closed drain tank which may be separate from or built into the ship's structure. Where the tank serves more than one compartment screw-down non-return valves should be fitted to the scuppers to prevent inter-communication between the compartments. Such an arrangement is especially useful for draining the after holds of refrigerated cargo vessels.

In passenger ships there may be one or possibly two power operated water-tight doors in the shaft tunnel between the stern gland and the watertight door on the after engine room bulkhead. In such cases, only that portion of the shaft tunnel situated between the stern gland and the aftermost watertight door is required to be watertight in relation to the compartments above. The section(s) of the shaft tunnel forward of this location may be regarded as part of the holds or compartments above. There is no objection to open scuppers

from these compartments being led to the shaft tunnel, provided the arrangements are such that the integrity of the watertight bulkheads is not impaired.

Cargo ships usually have a recess at the after end of the shaft tunnel forming a triangular-shaped flat in the after hold. In order to provide drainage for this flat, it is sometimes proposed to lead a scupper to the tunnel fitted with a self-closing cock. This is not acceptable, but by a simple modification it is possible to lead the scupper to the hold bilge forward of the recess, Figure 7. If this cannot be done, owing to the presence of wing deep tanks forward of the recess, the flat should be drained by means of a bilge suction led to the bilge main in the normal manner.

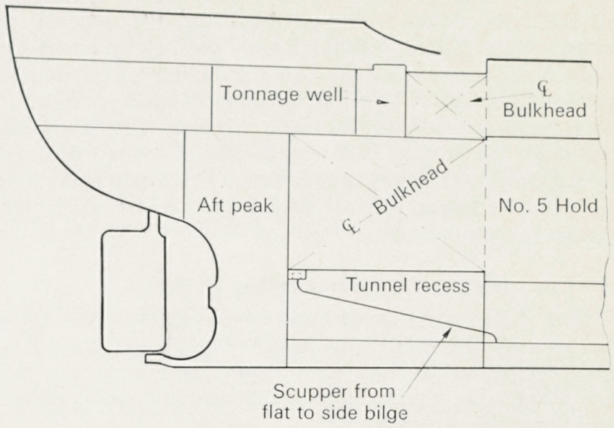


FIG. 7

Drainage from Aft End of Hold

3.7 Blanking Arrangements for Deep Tanks

When a deep tank is intended to carry water ballast, oil fuel or dry cargo, the Rules require provision to be made so that suctions not appropriate to the contents of the tank may be blanked off. Quite often an arrangement similar to Figure 8A is proposed, it being assumed that if a spectacle flange is fitted in the bilge line, and a change chest is provided for the oil fuel and water ballast lines, then everything is in order. Further consideration will show that, when the hold is carrying dry cargo, only one of the connections to the change chest can be blanked and that tank will, therefore, still be connected to either the oil fuel line or the water ballast line. To correct matters it would be necessary for a spectacle flange to be fitted in the combined OF/WB connection, so that both these lines are isolated from the tank when dry cargo is carried.

Figures 8B and C show better arrangements inasmuch as they are foolproof and considerably lessen the work of changing over the connections.

If, on occasions, vegetable oil or latex is carried in the tank, such cargoes will probably be handled by a shore installation,

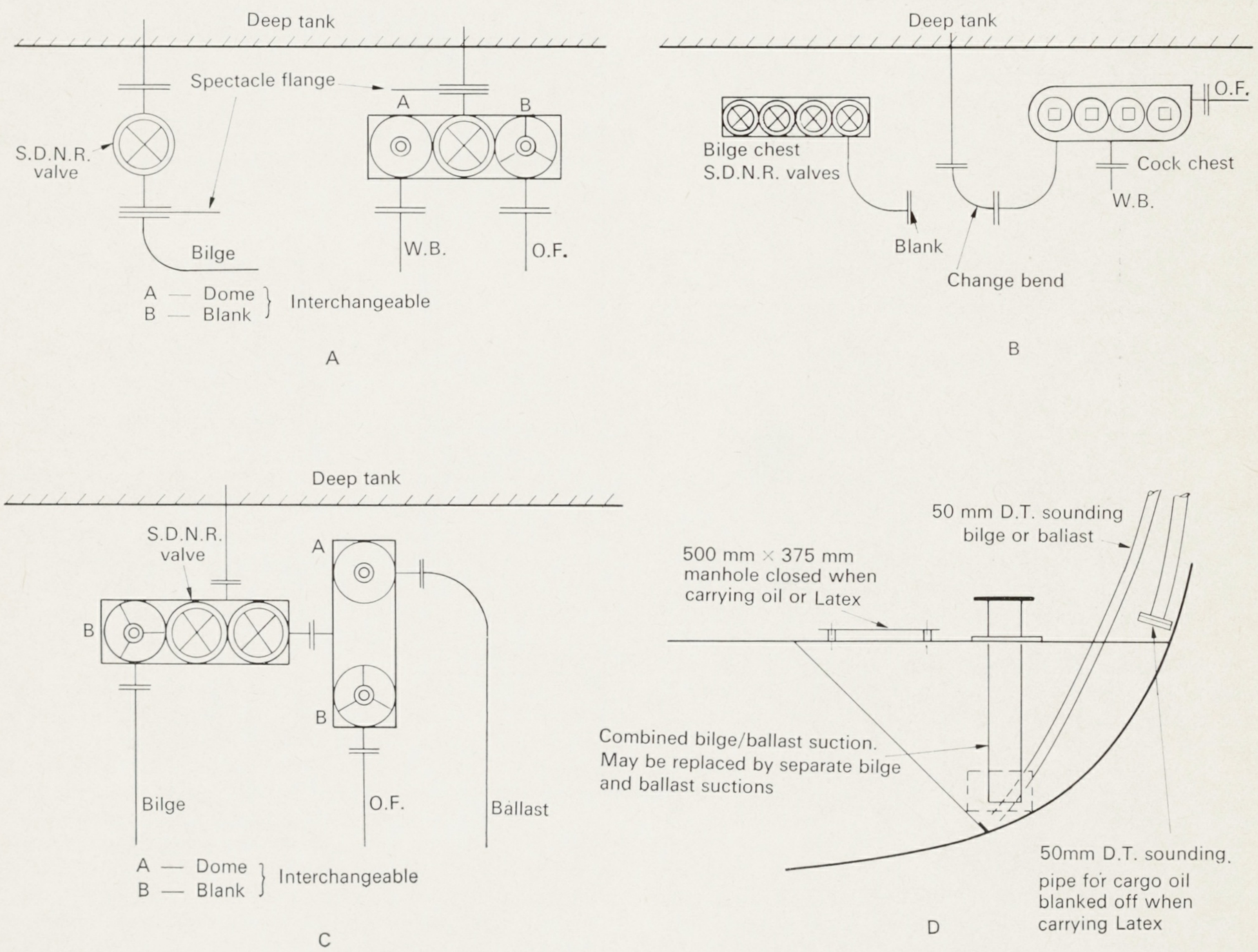


FIG. 8

Blanking Arrangements

and it will then be necessary to blank off the permanent suction(s) in the tank. This can be effected by closing the opening to the suction well, Figure 8D, and has the advantage of making it unnecessary to clean out the well or any part of the suction pipe(s) when the liquid cargo has been discharged.

It is recommended that air pipes to a deep tank which can be used for the carriage of dry cargo should not be fitted with filling connections. Cases have occurred in which a shore hose has been attached in error to such a connection, resulting in damage to cargo carried in the tank.

3.8 Compartments for Echo Sounding Devices

Many ships are fitted with an echo sounding device in a separate compartment in the double bottom. In most cases this compartment is very small and proposals to dispense with means of sounding, draining and ventilating the compartment have been accepted.

3.9 Closing Appliances for Air Pipes

It cannot be too strongly emphasized that, if closing appliances are fitted to tank air and overflow pipes in order to comply with Freeboard Regulations, they should be of a type which will open automatically when subjected to internal pressure. Wood plugs or other devices which can be secured closed are not considered acceptable, Chapter 13, 10.7.3.

Great ingenuity has been shown in the design of air pipe closing appliances but it is considered that the best arrangement, combining simplicity with safety, consists of a hood which can be placed in an open or closed position as desired. Figure 9 shows a sketch of this type of closing appliance, and in the closed position very little pressure is required to lift the hood and allow air or liquid to escape from the tank. Normally, the hood should be in the open position before the tank is pumped out, but in the event of failure to do this the slots in the hood should prevent the creation of a vacuum in the tank.

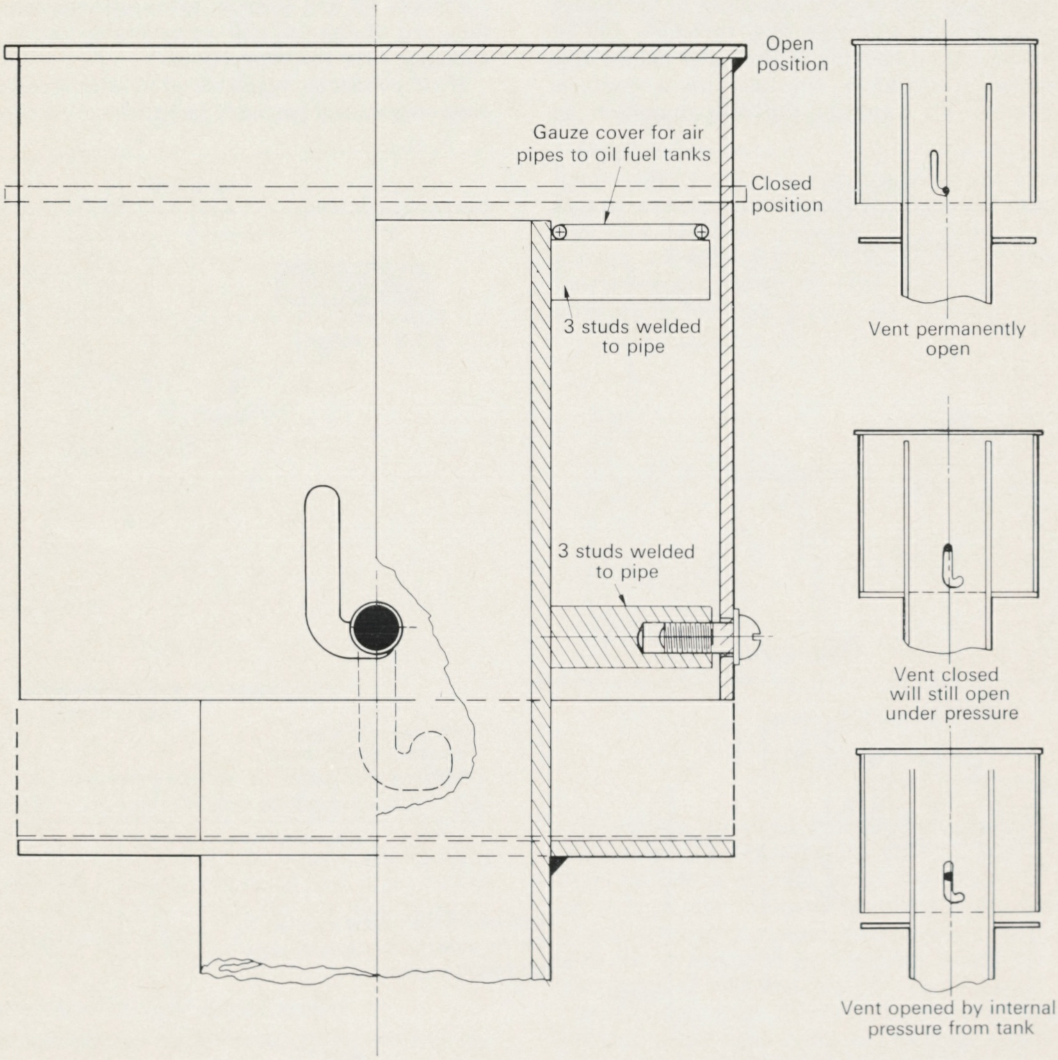


FIG. 9

Air Pipe Head

Alternatively, a common arrangement is to make use of a goose neck vent incorporating a floating ball shut-off valve. Also closely related is the need for gauze covers in the air pipes of oil fuel tanks. The Society's Rules and, as far as the Author is aware, the rules of other classification societies and similar bodies, require such covers to be fitted. The free area through the gauze should be not less than that of the respective air pipes.

It is possible for these fittings to constitute a hazard to the tanks they are intended to safeguard, as passage to and fro of oily vapour and any accumulated dirt or paint could result in the gauze becoming choked.

The Rules require that the gauze cover be readily removable for cleaning but there is no guarantee as to the frequency of any periodic cleaning operation.

The position is that, notwithstanding the care taken to ensure that the air and overflow pipe is of the correct size, a tank can be damaged through over-pressure simply because the air pipe has been blocked by the gauze cover becoming choked.

It is often requested that the size of gauze for these fittings be indicated. Although the Rules do not specifically state the size to be used, it is generally accepted that the gauze should be of 12×12 cm^2 mesh. Alternatively, gauze of 8×8 cm^2 mesh has been accepted provided that two layers of gauze are fitted with a spacer giving, say, not less than $12\frac{1}{2}$ mm gap between the layers.

3.10 Flooding of Holds

From time to time proposals are made by owners to flood one or two of the holds in order to ballast a ship when in light condition. Such proposals have been accepted in certain cases, subject to special precautions being taken. Each case should be submitted for consideration.

Particular attention should be paid to the proposed ventilation arrangements when holds are used for carriage of water ballast, having regard to possible damage during ballasting and de-ballasting should the venting arrangements be deficient.

4 PUMPING ARRANGEMENTS IN MACHINERY SPACES

4.1 Typical Bilge System for Vessels with Machinery Amidships and Aft of Amidships

The principal features of this system are the main bilge line, to which the bilge suctions from the various compartments are connected, and two bilge pumps arranged to draw from this line and direct from bilge suctions in the machinery space. In addition, there is an emergency bilge suction from the machinery space, commonly called the bilge injection, led to the main circulating pump or to the cooling water pump sea inlet line.

One branch and one direct bilge suction are fitted on each side of the machinery space. The direct bilge suctions should be of a size not less than that of the main bilge line in the machinery space. In motorships, the bilge injection should be the same size as the suction branch of the cooling water pump and in steamers it may be two-thirds of this size.

Some motorship owners are not keen on fitting a bilge injection to the salt water cooling pump, contending that there is a possibility of oil from the bilges being deposited on the internal cooling surfaces of the engine and thereby impairing the transfer of heat to the cooling water. To meet this objection, the Rules allow an alternative to a bilge injection in the form of an emergency bilge suction led to the largest available power pump which is not already fitted with a direct bilge suction having the same size as the suction branch of the pump. If this is a self-priming pump the direct bilge suction on the same side of the ship as the emergency suction may be omitted.

A typical bilge system diagram for the machinery space of general cargo ships is indicated in Figure 10, and is arranged and dimensioned to make it complementary to the plan of General Pumping Arrangements, Figure 2. This diagram illustrates the alternative to the bilge injection as described in the previous paragraph.

4.1.1 Bilge System for Vessel with Machinery Aft

The diagram of the bilge system in these ships is similar to that described in 4.1 except that it is difficult to legislate for the actual positioning of the various bilge suctions in the machinery space, and many cases have to be decided on their merits.

In large vessels there is generally a complete double bottom and it is customary for a branch bilge suction to be fitted in each of the forward wings and in the after well. However, these vessels are subject to large variations in trim and, as the amount of water which could accumulate in the wings in the event of a list is less than in the case of a vessel with machinery amidships, there is some justification for fitting the direct bilge suctions and the bilge injection at the fore and aft ends respectively of the machinery space. In practice, one direct bilge suction is often fitted in the after well, while the bilge injection and the other direct bilge suction are fitted at opposite sides of the forward end of the machinery space.

In smaller vessels of this type it is usual to have open floors in the machinery space, and since this compartment is in most cases comparatively short, the rise of floor is sharp enough at the forward end to make wing suctions unnecessary.

In such circumstances, the Rules require one branch and one direct bilge suction, plus the bilge injection, to be fitted on or reasonably near the centreline. There may, however, be a partial double bottom at the forward end of the compartment, and provided this is not too long and allows water to drain readily aft into the open floors, the number and arrangement of bilge suctions may be as required for open floors.

Figure 11 is a typical bilge diagram for the machinery space of a medium size oil tanker.

4.1.2 Bilge Suctions in the Machinery Space

Direct and branch bilge suctions in the machinery space and tunnel should be led from easily accessible mud-boxes fitted at platform level with straight tail pipes to the bilges. The intention is that foreign matter in the bilge water will be trapped in the mud-boxes, which are in a position to be quickly and easily cleaned.

In spite of this it is often proposed to fit a strumbox at the lower end of the tail pipe, which could become choked instead of the mud-box. To avoid this happening it is clearly stated in the Rules Chapter 13, 7.4.1 that strumboxes are not to be fitted in this position.

An open-ended pipe, bell-mouthed if possible, will ensure that the suction can be used to its fullest extent and, since it will only be required when large quantities of clean sea water have invaded the machinery space, the danger of choking is remote. However, in the event of the emergency bilge suction being led to a separate self-priming pump, as previously indicated, this suction should be provided with a mud-box. It will be appreciated that, in this case, the emergency suction may also be considered as the second direct bilge suction as required by the Rules.

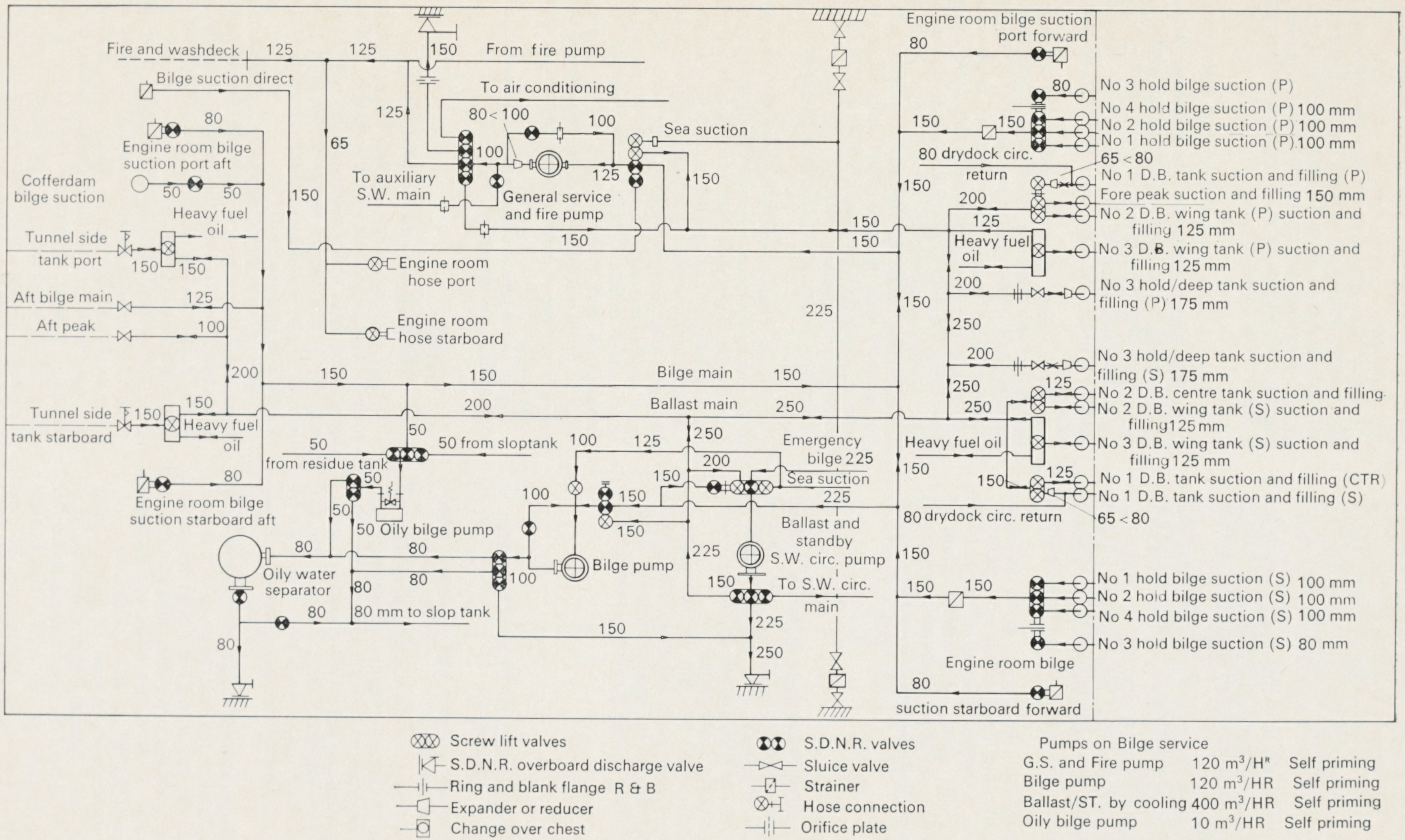


FIG. 10

Bilge System, Cargo Ship

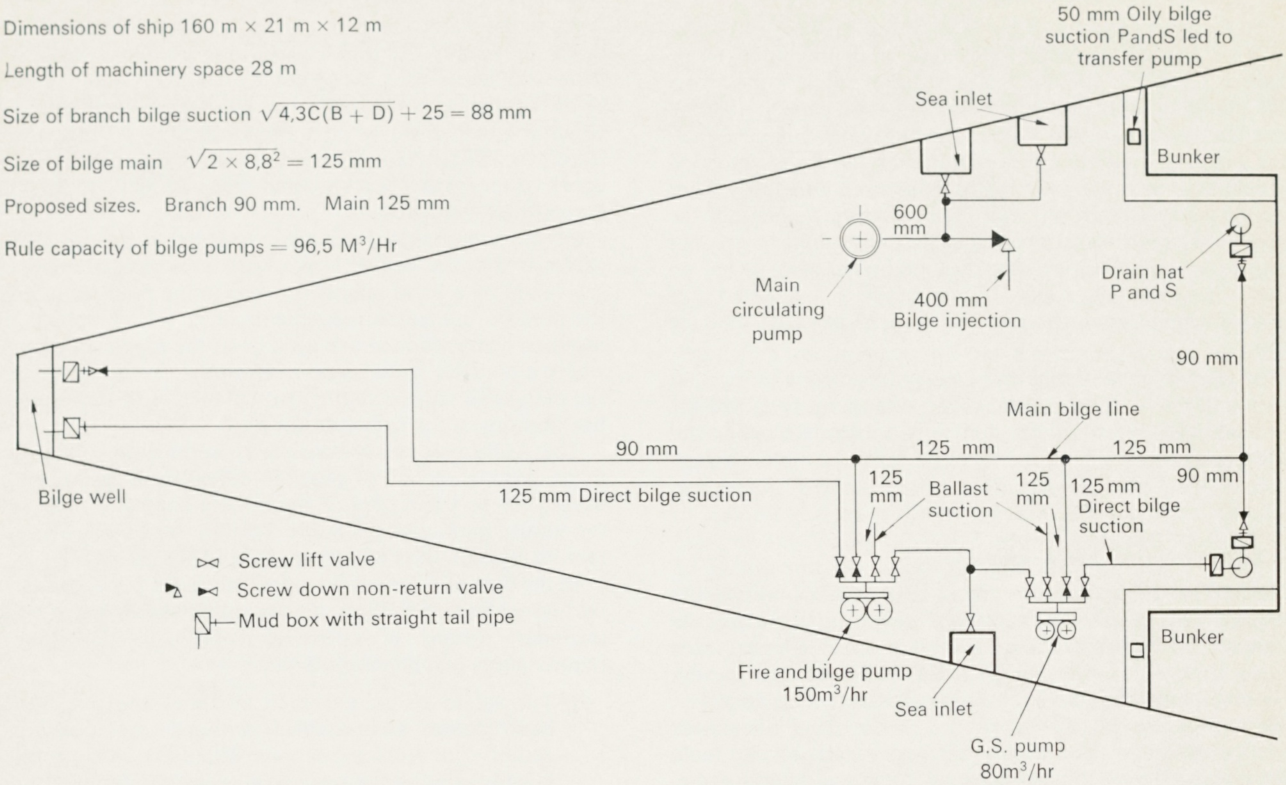


FIG. 11

Bilge System, Tanker

4.1.3 Bilge Pumps

In all self-propelled vessels, the Rules require at least two power operated bilge pumps to be provided in the machinery space. If there is a class notation restricting a vessel to harbour or river service, concessions are sometimes made and a hand pump may be accepted in lieu of one of the power pumps. The pumps may be used for ballast, fire or other general service duties of an intermittent nature, but should be immediately available for bilge duty, if required.

It may be thought unnecessary to mention that pumps which are normally in continuous operation on other services, such as salt or fresh water cooling systems, cannot be accepted as bilge pumps. It is essential that the Rule bilge pumps should be of the self-priming type or capable of being quickly and adequately primed by some independent means.

With the advent of motorships and the increased use of electrical power for auxiliary services, the centrifugal type pump has come to the fore. Generally these pumps are designed to be self-priming, but there are cases where ordinary non self-priming type centrifugal pumps are fitted in conjunction with a centralized priming system. This consists of a suitably constructed tank which is maintained automatically under a vacuum by air exhausting units, with connections led to the tank from each of the pumps concerned. Each pump can be put into communication with the vacuum tank by means of a control valve and, in addition, a special float-operated priming valve is provided to ensure that the liquid with which the pump is being primed will not be carried over to the vacuum tank. Further, a non-return valve may be fitted in the discharge branch to prevent entry of air from that side of the pump while it is being primed. Such an arrangement is acceptable provided there are not less than two air exhausting units and the whole system is thoroughly tested and proved satisfactory under working conditions.

Proposals to fit centrifugal pumps of non self-priming type, on the grounds that they can be primed from the sea, are not acceptable to the Society, although it is understood that such proposals have been accepted on occasions by other authorities.

There are various types of rotary displacement pumps on the market at the present time, and some of these have excellent self-priming characteristics. Further, either because of the rolling action of the working parts, or the use of special materials, or both, they are able to give years of good service as bilge pumps. Pumps of gear wheel type are not, in principle, considered suitable for bilge service. They may have a moderate suction lift when new, but the abrasive action of bilge water can quickly impair their efficiency.

An arrangement, which is growing in popularity, is the use of a bilge ejector supplied with high pressure water from an associated sea water pump in lieu of the independent powered bilge pumps. This arrangement has the advantages that the pump need not be self-priming and, as it is not contaminated by bilge water, it can also be used for services requiring a supply of clean sea water. The capacity of the ejector for bilge service is to be in accordance with the Rules.

The Society does not maintain a list of pumps approved for bilge service and acceptance of any particular pump is left to the discretion of the Surveyor, who is responsible for the pump during construction and testing at the maker's works. Final acceptance will depend on the pump's performance on the ship under working conditions.

Some notes on the survey of pumps during construction are given in Appendix I.

4.1.4 Capacity of Bilge Pumps

The required capacity of the bilge pumps will depend upon the Rule size of the main bilge line, and are indicated in Chapter 13, 6.3.2. As the Rules require not less than two bilge pumping units to be provided, the total capacity will be twice the figure indicated. One of the bilge pumping units may have a capacity less than that required by the Rules provided the deficiency is made good by the other unit. Obviously there must be a lower limit, otherwise the pumping capacity of the ship would be seriously impaired in the event of the larger unit being out of commission either through break-down or use on some other essential service. In general, it is considered that the lower limit should be not less than 70 per cent of Rule capacity.

The term bilge pumping unit usually means one pump, but either unit may consist of more than one pump provided the combined capacity of all the pumps is not less than the total Rule capacity.

4.1.5 Bilge Valves and Cocks

Since the bilge suctions from the various watertight compartments in the ship, including the machinery space, are connected to the main bilge line, it is essential that each suction should be controlled by a S.D.N.R. valve to prevent inter-communication between the compartments. Moreover, bilge pumps are usually required to draw from the sea or from ballast tanks, and to prevent water entering the main bilge line, or the machinery space via the direct bilge suction, the bilge valves in the pump suction chest should also be of S.D.N.R. type.

In small ships, cocks are often preferred to valves, and to obtain effective isolation of the sea or the ballast line from the bilge lines 'L' ported or open bottom single ported cocks are used. With cocks, however, there is always the danger of a flowback through the pump either from the overboard discharge connection at the ship's side or from the discharge of another pump.

To guard against such an occurrence, direct bilge suctions should be fitted with non-return valves, whether a cock is fitted at the suction branch of the pump or not. Exceptions to this general rule may be made in the case of reciprocating or other pumps having internal or external non-return valves, which would effectively prevent any flow-back through the pump.

4.2 Water Ballast Systems

When dealing with the system diagram, the sizes of the suction and filling connections to the various water ballast tanks should be checked with those shown on the General Pumping Arrangement plan, as it frequently happens that changes are made in the sizes. If any increases have been made, it may be necessary to draw attention to the fact that corresponding increases are required in the sizes of the air and overflow pipes to the tanks.

In some ships it is not uncommon for these tanks to be arranged for alternate carriage of oil fuel or water ballast. Also, it is considered that arrangements should be made for discharging any oil/water mixture overboard via an oily water separator. Indeed, it is a requirement of some national authorities that such provision is made.

In this respect attention is drawn to statutory regulations as issued by national authorities in connection with the International Conference for the Prevention of Pollution of the Sea by Oil 1954 and 1969 Amendments. A more recent Conference dated 1973 awaits ratification at this time.

4.2.1 Remote Control Valves

As indicated in Chapter 13, 2.3.3, ballast valves are to be fitted in readily accessible positions and, by implication, capable of being operated by hand. However, with the increase in use of remote control systems, plans have been received in which the ballast valves have been indicated as being located inside the ballast tanks. In order that such an arrangement could be accepted it is considered that two such valves should be provided in each tank.

Recent submissions have again reverted to the use of single valves within the ballast tanks, with provision for operating the valves by a hand operated pump in the event of failure of the remote control arrangements, e.g. power supply connections being made above deck or in the pipe duct or tunnel where a portable hand pump/compressor can be connected to the individual valve actuator. Acceptance of this arrangement has been given for ballast tanks only.

The Author does not necessarily agree with this arrangement, having regard to possible difficulty in draining these tanks, due to the failure of the remote control piping within the tank, particularly double bottom tanks or where the remote control pipes pass through hold spaces.

In the case of remote controlled valves for bilge, ballast and oil fuel systems in general, a hand pump can be accepted as a secondary means of operation subject to the following requirements being complied with:—

(i) The valves are accessible at all times and two portable hand pumps are provided at the control position together with full instructions displayed in a prominent position stating the operating procedure by hand pump.

(ii) A portable hand pump is provided in each compartment in which the valves are located, including duct keels and shaft tunnels, together with a notice in a prominent position as in (i).

(iii) The actuators used for heavy oil and diesel oil deep tank valves are of a type whereby opening of the valves by means of the hand pump does not render the remote control incapable of closing the valves.

It should be noted that the above arrangements would not be acceptable for a bilge valve arrangement on passenger ships, nor would they be accepted for direct bilge suctions or emergency bilge injections in the machinery space of any unrestricted class ship.

4.2.2 Separation of Bilge and Ballast Systems

An important requirement of the Rules for pumping arrangements is that the bilge system should be entirely separate and distinct from the ballast system, Chapter 13, 7.3.1. In small ships, the tanks carrying water ballast may be few in number, possibly only the fore and aft peaks, and there is a strong temptation to dispense with a ballast line and connect all suctions to the bilge line.

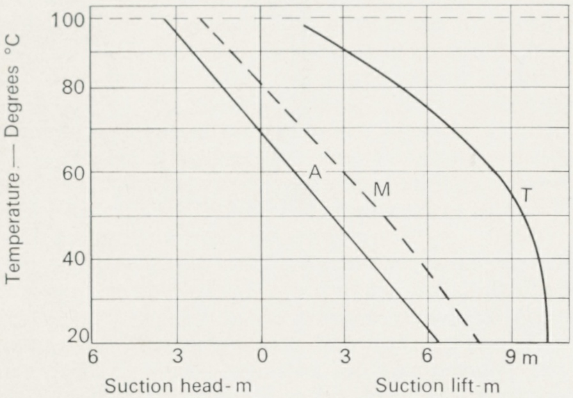
However, separate systems are necessary to enable the pumps to work simultaneously on both services and to prevent the ingress of water from the sea or from ballast tanks into dry compartments. It is accepted that many builders of small vessels have evolved standard pumping arrangements which are quite satisfactory, however there are arrangements which leave room for improvement.

Accordingly, it may be helpful to give some examples of pumping arrangements in the machinery space which would be suitable for small ships and these are discussed later in this paper.

It is, of course, necessary for the pumping arrangements to be tested on the completion of every ship and proved satisfactory and, in order to obtain good results, it is desirable that suction head lifts should be kept to a minimum. Attention is drawn in particular to this point, since experience shows that

estimates of the lifting capacity of pumps are frequently over-optimistic.

Further, the effect of temperature on the liquid being pumped is not always appreciated, and in this connection the curves, Figure 12, indicate the lifts which may be obtained with a reciprocating pump at various water temperatures. This information may be of assistance when pumping problems are under consideration.



A—Attainable suction lift estimated for a short pipe with one bend.

M—Maximum attainable under favourable conditions

T—Theoretical suction lift.

FIG. 12

Bilge Pump, Suction Head

4.2.3 **Overboard Discharge Valves**

It is a Rule requirement that all overboard discharge pipes from pumps should be fitted with a valve at the ship's side. The valves are to be of approved ductile material.

The type of pump will determine to some extent the type of valve fitted. The following valves are in general use:—

Butterfly valve
Sluice (gate) valve
Screw lift valve
Straight lift non-return valve
Automatic non-return valve

All the above valves are acceptable, but if any of the first three mentioned are fitted in association with positive displacement pumps, means should be provided to ensure that the discharge pipe cannot be subjected to excessive pressure in the event of the pump being started with the valve closed.

4.3 **Oil Fuel Systems**

4.3.1 **Adoption by the Society of 60°C as Minimum F.P. for Oil Fuel**

The Society first agreed to the burning of oil as fuel on a classed ship in 1898, and between then and 1902 several more oil-burning ships were built to class. At that time there were no Rules for oil burning, each case was dealt with on its merits and accepted with the proviso that the flash point of the oil fuel should be not less than 93°C.

In November 1901, following representation from an oil company, the Colonial Office decided to allow liquid fuel having a flash point not less than 65°C, to be used for ships' bunkers in Hong Kong harbour.

At that time the Rules for carrying and burning liquid fuel were being prepared, and after further enquiries it was decided to adopt a minimum flash point of 65°C in place of the 93°C figure as previously required.

It was some 70 years later before this was given further consideration and in 1971, after further discussion of the flash point, it was reduced to 60°C, as is now indicated in Chapter 14, 2.1.1.

4.3.2 **Oil Fuel Transfer System**

The use of oil fuel tanks which are also arranged to carry water ballast has already been mentioned. To enable transfer of oil to be made to the daily service or settling tanks at the same time as ballasting of tanks is in progress, it is usual to connect the tanks to two independent systems. This arrangement is a requirement of the Rules unless the service or settling tanks have a capacity sufficient for at least 12 hours' normal running without replenishment.

Further, since it is often desirable to use one line for water ballast and the other for oil fuel, valve arrangements are generally provided by means of which a tank can be placed in communication with one line and isolated from the other. Such arrangements are not, however, required by the Rules. In British practice a change-over chest having a dome and blank blisters is usually employed. Figure 13 shows such a chest. It will be readily appreciated that if the foregoing arrangements are to be effective, there should be a separate change-over chest for each tank.

Figure 14 is an arrangement adopted more or less as a standard by Scandinavian shipbuilders. The suctions from dual purpose tanks are led to cock chests by means of which the tanks can be connected to either of the two lines and two pumps are arranged to draw from and discharge to these lines. One of the pumps is primarily a ballast pump and the other an oil fuel transfer pump, but the ballast pump can serve as a standby to the transfer pump. With this system there are no tedious blanking arrangements and oil fuel can be drawn from and pumped into any one of the storage tanks should this be required.

4.3.3 **Standby Oil Fuel Transfer Pump**

Chapter 14, 4.1.1 requires that a standby transfer pump be provided if a power-driven pump is necessary for pumping up the settling tanks, but this does not necessarily mean that there must be two transfer pumps. In oil burning steamers it is a simple matter to arrange one of the unit pressure pumps as a standby transfer pump, but in motorships there is often some doubt as to how the requirement can be met.

If a motorship burns heavy oil in the main engines and diesel oil in the auxiliaries, it is quite likely there will be a separate transfer pump for each system. The suction and discharge sides of these pumps can be cross-connected and isolating valves or spectacle flanges may be fitted if it is desired to keep the systems separate. In an emergency the blanks can be changed, enabling either pump to take over all transfer duties. The essential feature about a standby transfer pump is not that it should be able to undertake all the duties of the working pump, but that it should be able to draw oil from any of the storage tanks and discharge it to the service or settling tanks in sufficient quantity to keep the machinery working. Accordingly, if the oil fuel purifier pumps which discharge to the daily service tanks are arranged to draw from the oil fuel main, they may be regarded as fulfilling the purpose of a standby transfer pump. A hand pump may also be accepted for this duty provided it is of sufficient capacity, but it is considered that the total maximum power of the engine should not exceed, say, 2220 kW.

In all cases, oil fuel pumps, with the exception of the hand pump referred to above, are to be provided with relief valves in closed circuit and are to be capable of being stopped from outside the compartment in which they are situated.

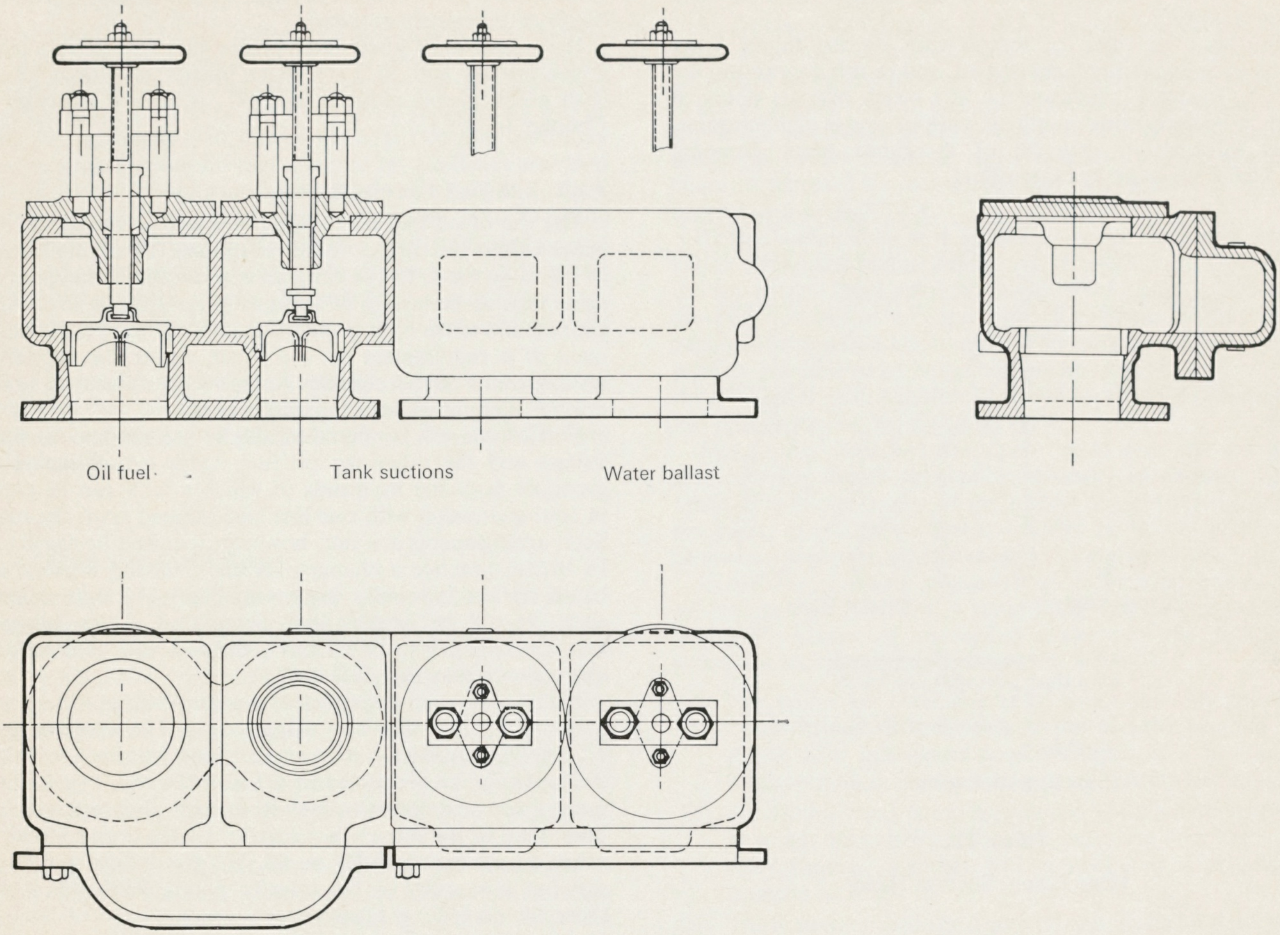


FIG. 13

c/o Arrangement

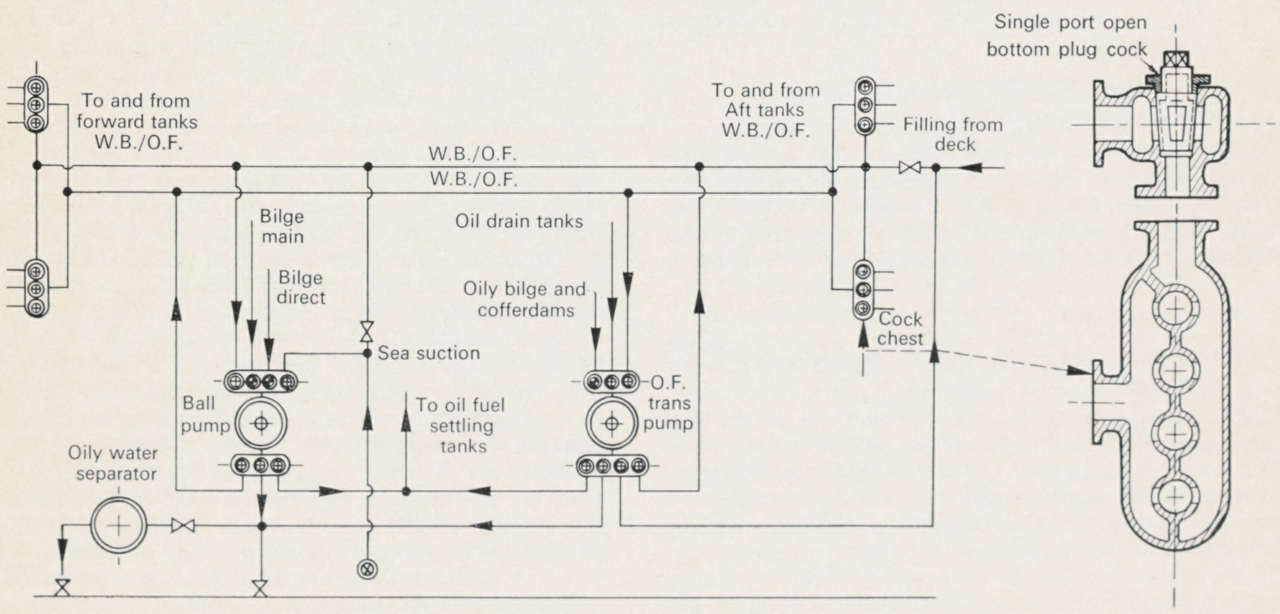


FIG. 14

c/o Arrangements: Scandinavian

In the case of passenger ships the arrangements are to be such that oil fuel can be transferred from any fuel oil storage tank or settling tank to any other oil fuel storage or settling tank, Chapter 14, 4.12.1. This, in reality, requires separate suction/filling lines to each tank.

4.3.4 **Outlet Valves Fitted on Oil Fuel Deep Tanks**

Outlet valves on oil fuel deep tanks should be of steel or other approved material, and are to be capable of being closed locally and also from positions outside the compartment in which the tank is located. In the case of oil fuel daily service tanks and settling tanks, individual control of the outlet valves should be provided. These valves should not be operated by a single control which operates a number of valves. Further, a failure of the remote control for these tanks should not cause the valve to fail shut since this could possibly hazard the ship, e.g. failure and closing of the oil fuel supply to the engines in a restricted sea-way.

Plans showing the outlet valves on the tanks connected to a common remote control system have been submitted, but such an arrangement could only be considered acceptable when used in conjunction with deep storage tanks, other than service/settling tanks, provided the arrangements are such that the valves are arranged to fail shut on failure/loss of the control pressure. In all cases, the valves are to be capable of local manual operation independent of the remote control mechanism. Consideration may be given to the omission of the remote control of outlet valves in the case of small tanks whose capacity does not exceed 450 litres.

4.3.5 **Filling Connections on Oil Fuel Deep Tanks**

If filling connections are not led to the top of oil fuel deep tanks, they should be fitted with S.D.N.R. valves secured to the tank plating. Alternatively, a screw-lift or sluice valve may be used provided it is controlled as previously indicated.

4.3.6 **Oil Burning Units**

It is generally understood that the oil fuel pressure pumps, as required by Chapter 14, 3.1.1, should be independently driven. Nevertheless, proposals have been received in which one of the pumps has been driven by the main engine. This pump would, of course, be useless if the ship were manœuvring and such a proposal is not acceptable.

Further, it is sometimes thought that, in the case of a duplex unit, a single clean-in-service filter can be substituted for either two suction or two discharge filters of the ordinary type. Again, this is not acceptable and the filters should be duplicated, irrespective of the type fitted.

In the case of top fired boilers, means are to be provided in order that, in the event of flame failure, the oil fuel supply to the burners is shut off automatically, and audio-visual alarm given. In all cases the arrangements are to be such that the oil fuel is shut off before a burner can be withdrawn. Provision is also to be made, by suitable non-return arrangements, to prevent oil from spill systems being returned to the burners when the oil supply to the burners has been shut off.

4.3.7 **Steam Purging Systems**

Steam purging of oil fuel burners is not uncommon on modern high pressure boilers: sometimes they may be hand operated or, alternatively, there may be an automatic system. Chapter 14, 3.4.1 requires that the arrangements are such that oil fuel cannot enter into the steam system in the event of a valve leaking. However, it has been known for oil fuel to enter a low pressure steam system due to faulty/sticky non-return valves in the common pipe length. In the circumstances, it is considered that a drain valve should be fitted in the steam line before it joins the common fuel steam supply line to the burners.

The drain valve should be interlocked with the steam control valve in such a manner that when the steam valve is closed the drain valve will be opened and vice-versa. The drain pipe is to be led to a readily visible and safe position where no danger could occur in the event of leakage from the pipe. In the case of automated purging systems, the oil fuel and steam purging supply valves may also require to be so interlocked.

4.3.8 **Heated Oil Under Pressure**

As indicated in Chapter 14, 4.5.1, pipes conveying heated oil under pressure are to be located in readily visible and accessible positions.

Further, with reference to diesel units, Chapter 2, 7.1.1 requires that high pressure fuel injection pipes be adequately shielded and secured in the case of engines having a cylinder bore of 250 mm and over.

In the case of unmanned engine rooms, such pipes are to be shielded and secured irrespective of the cylinder bore size as indicated in Chapter 2, 7.1.3.

4.3.9 **Quick-Closing Master Valve on Hot Oil Supply**

This valve is required by the Rules to be fitted on the hot oil supply to the boiler manifold. It is believed that the valve should necessarily be of a type capable of being controlled from outside the machinery space. This is not the case, as the valve is only intended for local operation in an emergency. It may be an ordinary valve having a spindle with a very coarse thread to permit rapid closing. Alternatively, a lever-weighted straight-through cock could be used, the lever being normally in the 10 o'clock position with the cock open and in the 2 o'clock position when closed.

4.3.10 **Downcomer Pipes from Daily Service and Settling Tanks**

The regulations of some countries require that means are to be provided for rapidly emptying the daily service and settling tanks, situated in the upper part of the machinery space, in the event of fire in this compartment. Naturally, space must always be available into which the oil can be discharged, and it is sometimes proposed that the cofferdam in way of double bottom tanks under the machinery space should be used for this purpose. Such proposals have been accepted, as the advantages of being able to dump the oil in an emergency outweigh the disadvantages of using the cofferdam. This space will require a suction led to the oil fuel main or to the transfer pump so that the oil can be removed after the emergency.

4.3.11 **Sounding Arrangements for Daily Service and Settling Tanks**

The desirable capabilities of any apparatus employed for indicating the level of oil in these tanks may be summed up thus:—

(i) Safety.

(ii) Reliability.

(iii) Simplicity.

In general terms, the apparatus falls into one of the three following categories:—

(i) Gauge glasses.

(ii) Float indicating gear.

(iii) Contents gauges.

The general attitude regarding level gauges on fuel tanks is that failure of a sounding device or over-filling of a tank must not permit release of fuel. It is understood that proposals before the Inter-Government Maritime Consultative Organization (I.M.C.O.), may prohibit the use of round gauge glasses,

but a government administration may permit the use of level gauges incorporating flat glasses and self-closing valves. The flat glass gauge would require to be of heat resistant type, such as Pyrex, and adequately protected against mechanical damage. It may be well to add that the requirements of Chapter 13, 10.11.5 are also applicable to lubricating oil tanks, as lubricating oil released onto a hot surface is immediately flammable.

4.3.12 Float Indicating Gear

In most designs, the wire which is attached to the float passes through a hole in the top of the tank, and it is possible for leakage to take place at this point should the tank be overfilled. In one particular case such leakage resulted in the loss of the ship by fire. To prevent leakage the wire should be as close a fit as possible in the hole, and an overflow pipe should be fitted to the side of the tank near the top so that the underside of the top plating is not subjected to pressure.

4.3.13 Contents Gauges

These gauges may be accepted provided they are of an approved type and are found satisfactory when tested after installation on board the vessel. Like all instruments, however, they are liable to malfunction at times, and for this reason a sounding pipe is usually provided as an alternative means of ascertaining the level of oil in the tank. Such a sounding pipe should be fitted with a self-closing cock with a parallel plug.

4.3.14 Starting-up Units

Chapter 14, 3.3.1 requires a hand pump or other suitable device to be provided for starting up a unit from cold, and occasionally it is proposed to fit an electrically driven pump in place of a hand pump. This is in order, provided the electric power is supplied by an emergency generator, or any other generator which can be started by hand, or by means of compressed air supplied from a hand compressor.

4.3.15 Steaming-out Connections

Whilst on the subject of fittings for oil fuel tanks mention must be made of the steaming-out connection.

In most cases this connection consists of a permanent pipe led from a convenient point on the tank heating steam line to a valve secured to the side of the tank. This valve should be of S.D.N.R. type, and in addition, a spectacle flange should be fitted so that the connection can be blanked off again after use. These precautions would be adequate if the blank were re-inserted after use, but experience has shown that this is not always done, nor is the valve always of the S.D.N.R. type.

It is considered that either of the following arrangements would be superior to that of the above:—

(i) The use of a valve and spectacle flange fitted in an accessible position, from which a pipe is led into the top of the tank, or:

(ii) provide an S.D.N.R. valve on the side of the tank which can be connected by a flexible hose to another valve at a suitable point on the steam line. After use the hose is removed and special caps, secured by chains, can then be screwed on to the open ends of the valves. It is most unlikely that the hose would be left in position and, once the connection was broken, there would be no possibility of oil fuel entering the steam system.

4.3.16 Temperature of Oil Fuel in Tanks

Whilst the Society has no Rules regarding the upper temperature limits for oil fuel in tanks, it is desirable for tanks built into the ship's structure that the temperature should not exceed 48°C. Higher temperatures are in order for daily service or settling tanks, which are not part of the ship's structure. In such cases it is considered that the margin between the temperature of the oil and its ascertained flash point should be not less than 10°C.

Thermometers for recording the temperatures should be provided for the tanks, but thermostatic control is not required.

4.3.17 Separate Oil Fuel Tanks

These tanks are constructed in a variety of shapes and sizes and, at the present time, most firms have evolved a few standard designs which are based upon proven experience over a number of years.

Occasionally, plans of tanks are received which show a serious deficiency in plate thickness and/or stiffening arrangements, indicating that the principles of tank design are not understood. Tanks constructed to such plans would suffer badly from distortion when tested to quite a moderate head.

Normally, plans of oil fuel tanks are forwarded to Head Office for approval, but in certain circumstances, it may be necessary for them to be dealt with locally, then the table shown in Figure 15 may be used. It can be seen that for various thicknesses of plating and heads of oil a breadth of panel is indicated. This is the maximum distance allowed between continuous lines of support, which may be stiffeners, washplates or the actual plating of the tank.

THICKNESS OF PLATE	HEAD FROM BOTTOM OF TANK TO TOP OF OVERFLOW PIPE IN METRES				
	2,5	3,0	3,7	4,3	4,9
MM	BREADTH OF PANEL IN MM				
5	585	525			
6	725	645	590		
7	860	770	700	650	
8	1000	900	820	750	700
10	1280	1140	1040	960	900

FIG. 15

OIL FUEL TANK SCANTLINGS

In general, the minimum thickness for the plating of oil fuel tanks is to be not less than 5 mm, but for small tanks it may be reduced to 3 mm.

It is not a simple matter to lay down hard and fast rules for the dimensions of the stiffeners of these tanks, but examination of a large number of plans suggests the following proportions as suitable:—

Thickness of stiffener = Thickness of plating or 6 mm, whichever is the greater

Depth of stiffener =

$$\frac{\text{Breadth of panel as per table}}{10} + 12 \text{ mm}$$

Maximum unsupported length of stiffener = 2 × breadth of panel as per table

If the length of the stiffener exceeds twice the breadth of the panel, transverse stiffeners should be fitted or, alternatively, tie-bars should be fitted between stiffeners on opposite sides of the tank.

4.3.18 Oil Fuel Overflow Systems

When dealing with plans for oil fuel overflow arrangements, the following essential requirements must be borne in mind:—

(i) The overflow pipes must be of sufficient size to allow the oil to escape at the same rate as it is being pumped into the tank. To ensure this, the Society's Rules require the overflow pipes to have a cross-sectional area not less than 1.25 times that of the filling pipes.

(ii) The overflow pipes must not rise to a point which gives a head higher than that for which the scantlings of the tanks are suitable.

(iii) The overflow pipes must be led to a suitable overflow tank.

(iv) The overflow pipes must not be fitted with valves or cocks which can prevent overflow taking place.

Air pipes may serve as overflow pipes for oil fuel tanks provided they terminate in a safe position in the open above the bulkhead deck. However, with this arrangement, in the event of a tank being over-filled, there is always the possibility of oil being deposited on the deck.

If an overflow system is to be provided for the oil fuel storage tanks it may either be included on the plan of air and sounding pipes or may be shown on a separate plan. The aim in such a system should be to obtain the simplest arrangement possible consistent with the adequate safeguarding of the tanks. With regard to sizes, it has been the Society's practice for many years to require the size of the overflow main to be of sufficient cross-sectional area at any part of its length to allow any two tanks to overflow simultaneously. Figure 16 shows a typical overflow system.

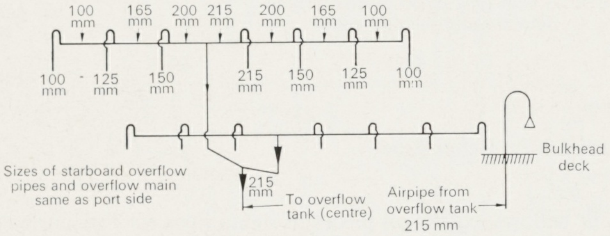


FIG. 16

Air/Overflow Arrangements

The individual overflow pipe from each tank should have a cross-sectional area 1.25 times that of the filling pipe, and it should rise to a point close to the bulkhead deck before joining the appropriate main. The mains should be situated well above the deep load water line and increase in size from each end in accordance with the principle explained previously, to a point where downcomer pipes are led to the overflow tank.

The overflow tank should be filled last during the bunkering operation. It is desirable that an alarm device should be fitted in each tank at a level which will leave a reasonable amount of space for eventualities. As a final precaution against structural damage to an overflow tank, an air pipe should be led to deck in the normal manner.

The overflow main is to be situated well above the load water line in order to comply with Chapter 13, 10.10.2. If an overflow main serves tanks in two or more watertight compartments, and is situated below the load water line, the branches from the tanks should be fitted with non-return valves to prevent sea water from a damaged tank passing to other tanks via the overflow main. In addition, the tanks should be provided with air pipes to prevent them being subjected to a vacuum when they are pumped out.

4.3.19 Limitation of Filling Pressure by Relief Pipe

Figure 17 shows an arrangement sometimes employed, which consists of a relief pipe branching off the filling main in the lower part of the machinery space. This pipe, having cross-sectional area 1.25 times that of the filling pipe, is led to the upper deck level and then dropped down to the overflow tank. A vent is led from the top of the relief pipe to the open air at bridge deck level and an alarm is fitted in the relief pipe and in the overflow tank.

The filling pressure cannot exceed that of the head of the relief pipe. Therefore, this arrangement is probably only suitable where the oil fuel is carried in double bottom tanks or shallow deep tanks. With deep tanks of full height the bunkering operation would be too slow owing to the small pressure differential.

In view of the relief pipe, the size of the air pipes to the tanks is relatively unimportant, assuming that the tanks are intended to carry oil fuel only, but the air pipes should be led to a position somewhat higher than the top of the relief pipe.

It will be noted that Chapter 14, 4.11.2 requires that provision is made against over-pressure in the filling lines, also that the filling station is isolated from other spaces and adequately drained and ventilated, Chapter 14, 4.11.1.

4.3.20 Prevention of Water Ballast Entering Overflow Systems

When tanks arranged for the carriage of either oil fuel or water ballast are connected to a common overflow main, it is necessary to provide arrangements for preventing water ballast overflowing into tanks containing oil fuel, as required by Chapter 13, 10.10.3.

Paragraph 4.3.19 points out that the size of the air pipes fitted to oil fuel tanks is relatively unimportant, in association with a relief pipe on the oil fuel filling main. In the event, however, of any of the tanks being intended to carry water ballast alternatively with oil fuel, the air pipes should be of Rule size when a connection is fitted to the ballast system. Air pipes below Rule size are in order when the tanks can only be flooded from the sea.

4.3.21 Overflow Arrangements for Daily Service and Settling Tanks

On account of the frequency with which it is necessary to transfer oil fuel to the daily service or settling tanks, it is desirable that such tanks should have overflow pipes in addition to the air pipes, and this is indicated in Chapter 12, 10.9.2. The overflow arrangements should be shown on the diagram of oil fuel service piping in the machinery space and should be of a simple character.

In smaller motor vessels having one or two daily service tanks, the overflow pipes from these tanks are usually led direct to one of the storage tanks.

In larger ships there may be several service and settling tanks, each provided with a separate overflow system which, in many British-built ships, is led to an overflow tank in the lower part of the machinery space, alarm devices being fitted in the overflow pipes. Figure 18 shows such an arrangement. Oil fuel is often carried in double bottom tanks under the machinery space and these can be used as overflow tanks. However, audio-visual alarm devices are to be fitted to give warning that part of the tank reserved for overflow purposes is being encroached upon. It is considered that the space reserved for overflow purposes should be sufficient for not less than 10 minutes' pumping at normal bunkering capacity.

An alternative arrangement, with regard to service/settling tanks, is to provide a common breather pipe in conjunction with an overflow system from these tanks. Figure 19 shows an arrangement which could be considered acceptable. It should, however, be added that when checking the sizes of the overflow pipes from the tanks no allowance should be given to the size of the breather pipe, which is not considered as part of the overflow system.

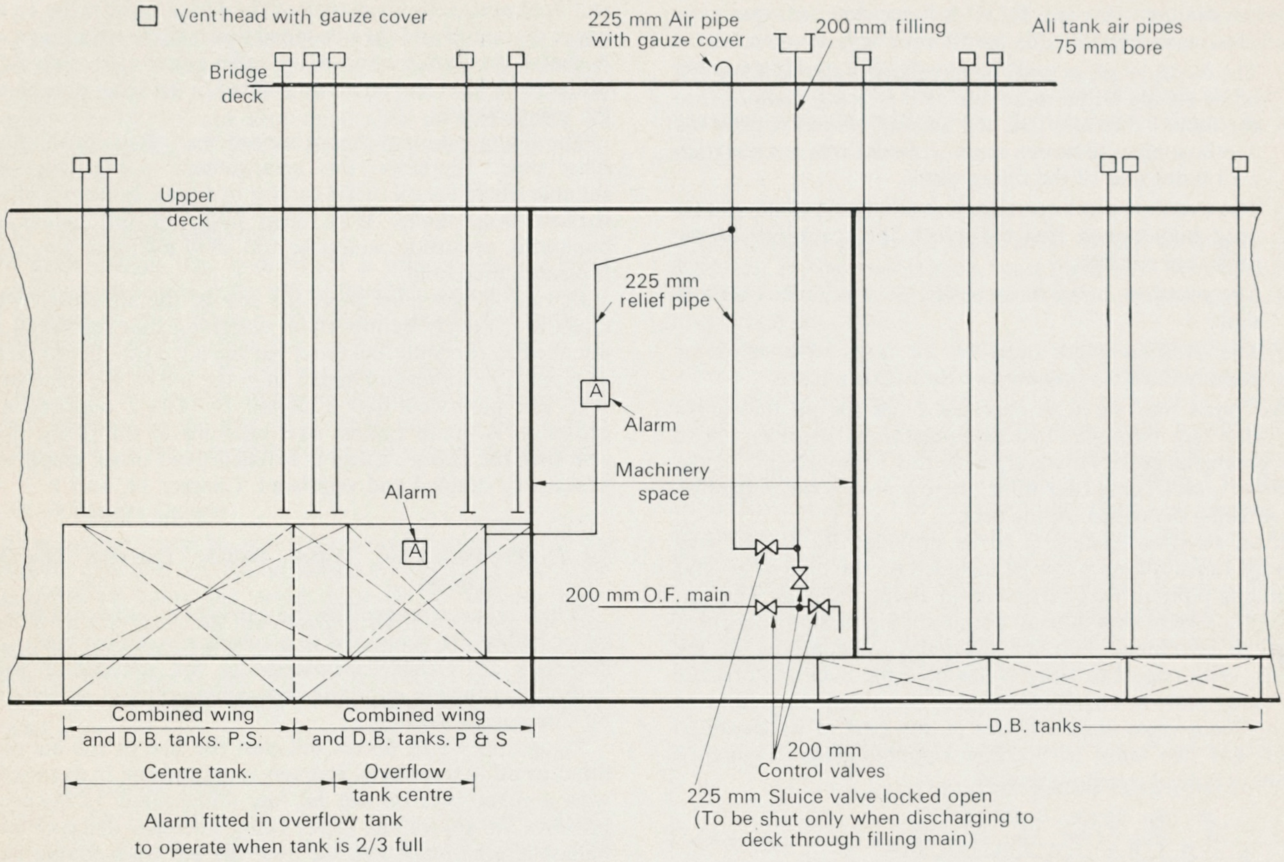


FIG. 17

Limitation of Oil Fuel Filling Pressure by Relief Pipe

4.3.22 **Drip Trays**

Drip trays or their equivalent should be fitted under separate oil fuel tanks, oil fuel units, pumps, heaters and other fittings from which leakage of oil might occur. All such trays, with the exception of the smaller variety which can be readily cleaned out, should be drained to an oily bilge or to an oil drain tank provided for the purpose.

It is sometimes proposed to lead the drain from a drip tray under a separate oil fuel tank into the overflow pipe from the tank. This is regarded as bad practice, as it is possible for the overflow pipe to become choked or partially choked by waste or other foreign matter from the drip tray. This might lead to overflowing oil backing up into the tray and descending on to heated surfaces of the machinery below. For this reason tray drains should be led separately to the oily bilge or to an oil drain tank, as previously indicated.

4.3.23 **Oily Bilge Suctions**

Oily bilge suctions may be led to a separate oily bilge line terminating in a master valve at the transfer pump or other suitable pump. They should not be connected to the oil fuel main, it being obvious that if foreign matter is lodged under a valve lid, as frequently happens with oily bilge valves, oil fuel will flow back into the bilges when the line is subjected to a head of oil, either through the opening of a deep tank valve or when filling from deck.

4.4 **Steam Piping**

Chapter 14, 5.1.1 requires that provision be made for expansion and contraction of steam pipes. It is not unusual to fit bellows expansion pieces in steam lines for this purpose and, whilst no objection is seen to this arrangement, certain points in connection with these fittings must be considered:—

(i) The bellows should be protected against over-extension and excessive compression.

(ii) The adjacent pipes and fittings must be suitably anchored and supported.

(iii) The bellows pieces should be protected against mechanical damage.

(iv) Where flow is in one direction only it is considered desirable to have an internal guide, in order to protect against internal erosion due to possible eddies and turbulent flow in way of the convolution.

4.4.1 **Drainage of Steam Pipe Systems**

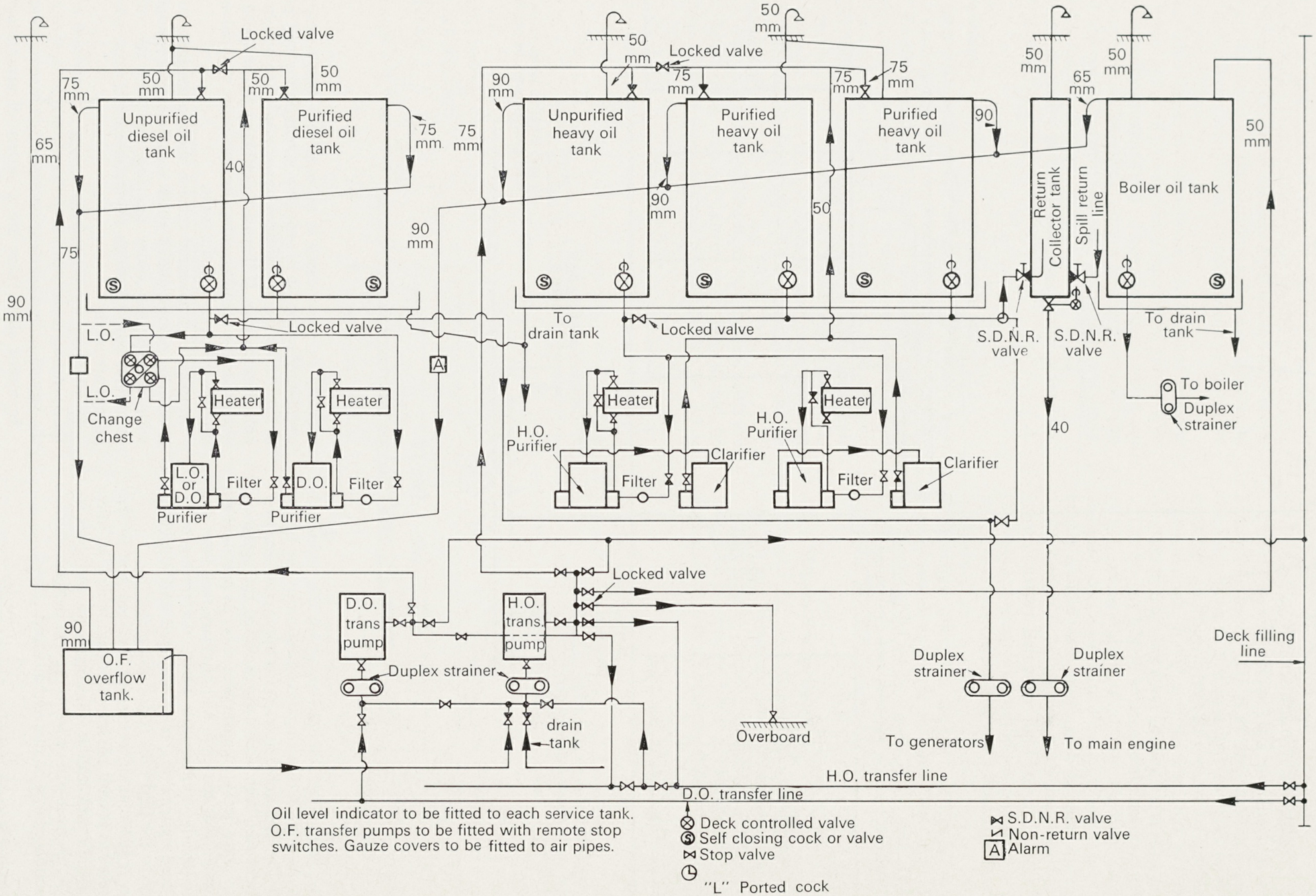
Chapter 14, 5.2.1 requires that provision be made for draining water from the steam pipes, as serious damage has been known to occur due to the accumulation of water caused by lack of effective drainage.

4.4.2 **Heating Coils**

In the case of tankers, the supply and return pipes to and from the heating coils should always be fitted above deck between the engine room and the cargo tanks.

4.5 **Feed Systems**

As indicated in Chapter 14, 6.2.1, two separate means are to be provided for the supply of feed water to all main and auxiliary boilers.



Oil level indicator to be fitted to each service tank.
O.F. transfer pumps to be fitted with remote stop switches. Gauze covers to be fitted to air pipes.

FIG. 18

Oil Fuel System

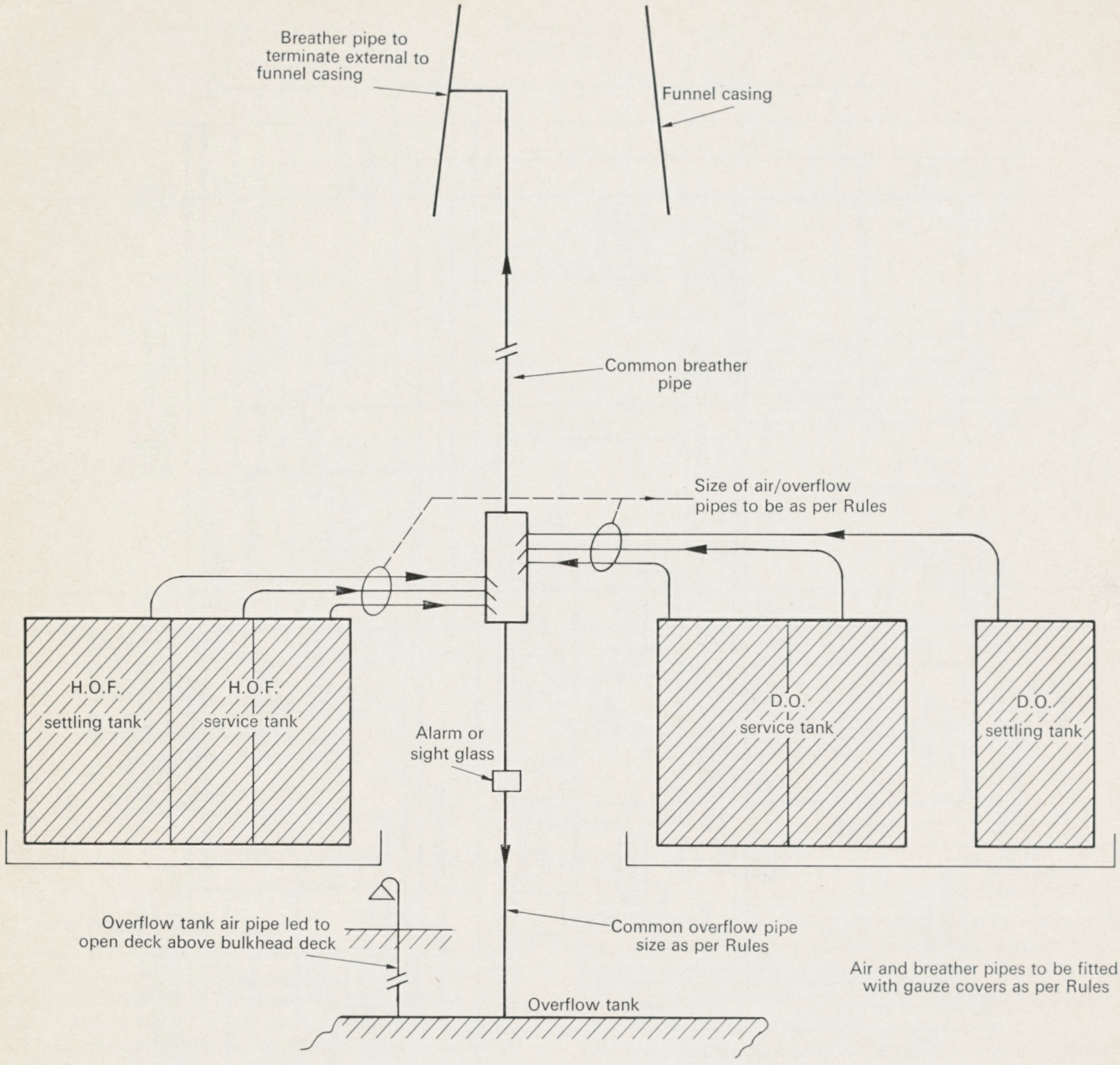


FIG. 19

Oil Fuel System Common Breather Pipe

Occasionally, plans are submitted on which the main and auxiliary systems are led to a single connection to the boiler steam drum or the economizer inlet. After some consideration this arrangement has been accepted, provided the common stub piece is of extra heavy gauge and as short as practicable. It should be noted that the main and auxiliary feed lines are led separately to the boiler stub piece. An arrangement whereby the feed systems are interconnected and led via a single feed line to the feed inlet is not acceptable.

It has been noted that on occasions the feed line to the economizer unit has several passes, each pass having an inlet and outlet valve. In such cases it is necessary for each pass to be fitted with a relief valve in order to prevent damage should the inlet and outlet valves be inadvertently left closed.

4.6 **Cooling Water Systems Standby Arrangements**

In steamers of moderate power, the ballast pump is usually arranged as the standby cooling water pump, and whilst its capacity in most cases is considerably below that of the circulating pump, it is probably adequate for half power or at least to maintain sufficient power needed to obtain reasonable steerage way. If there are doubts as to the speed obtainable with the standby pump in operation, it is advisable to determine this during the trials.

Modern high powered turbine ships often have two main circulating pumps, one of which is sufficient for normal power with average sea water temperatures and the other for maximum power or high sea water temperature, when both pumps are used.

In addition, the arrangements may incorporate a 'scoop' for operating under normal running conditions, thus enabling the pumps to be shut down except when manœuvring.

In motor ships there are a variety of arrangements that can be used, depending to a large extent on whether the engines are fresh or salt water cooled. In larger ships it is usual to fit three cooling water pumps, one for fresh water,

one for salt water and the remaining pump as a standby for either service. In smaller motorships a standby fresh water pump is frequently omitted, and the arrangements are such that the engines can be circulated with salt water in the event of a breakdown of the fresh water pump.

From the foregoing it will be seen that, in all cases, an alternative supply of salt cooling water should be available. Where the diesel engines have attached pumps, the bilge pump is generally arranged as the standby salt water circulating pump. Alternatively, this duty can be undertaken by a suitable general service pump.

Another alternative to the permanently installed standby cooling water pump and its ancillary piping and valves, is to provide a standby pump carried on board as spare which can be easily and readily installed, and this arrangement has been accepted for use in conjunction with multiple power units, Chapter 14, 7.2.2b.

In all cases provision is to be made against over-pressure in the cooling water system.

4.7 Sea Inlets

Salt water circulating pumps are generally connected to a common suction line led to low sea inlet valves on opposite sides of the engine room. If the vessel is engaged on a trade which necessitates the navigation of shallow muddy rivers, it is usual for one or two high inlet valves to be fitted in addition to the low inlets. Alternatively, a compromise is sometimes effected by raising the low inlets to a point in between the normal low and high positions. This is acceptable provided that they are situated where they will be submerged under all service conditions.

It should be noted that not less than two low sea inlets are required for cooling water purposes, and they should be independent of each other as required by Chapter 14, 7.5.1. An arrangement in which the main and standby cooling water pumps can only draw from two inlet valves which are attached to a single sea chest or reservoir is not acceptable.

4.8 Ice Navigation

4.8.1 Cooling Water Returns to Sea Inlets

For a ship with an ice class notation it is necessary for a connection to be led from the cooling water overboard discharge lines to the main and auxiliary cooling water sea inlets. In addition, where no steam is available for clearing purposes, the fire pumps are required to have a suction connection from the main cooling water inlet pipe.

The Society has no specific requirements regarding the size of the cooling water return to the sea inlet, but it is generally accepted that this should be not less than $\frac{2}{3}$ of the main engine cooling water overboard discharge line.

The exception to this is when the ice class notation required is for Northern Baltic Service, Chapter 9, 2.16. In such cases, the cooling water return to the sea inlet must be the same size as the main engine cooling water discharge overboard line.

Figure 20 shows a suggested cooling water arrangement for a motorship, indicating these connections. It will be observed that all sea water supply is drawn from a single sea suction line having inlets on both sides of the ship. This pipe should be of generous size, while the continuous demand for water will assist in keeping the inlets free.

4.9 Shipside Connections

Chapter 13, 2.6.3 requires that all shipside sea inlet valves and sea inlet boxes are fitted with gratings.

There is now a British Standard for such gratings, BS MA 62 'Weed Grids for Sea Inlets'. This indicates that the grating bars should lie in a fore and aft direction evenly spaced with

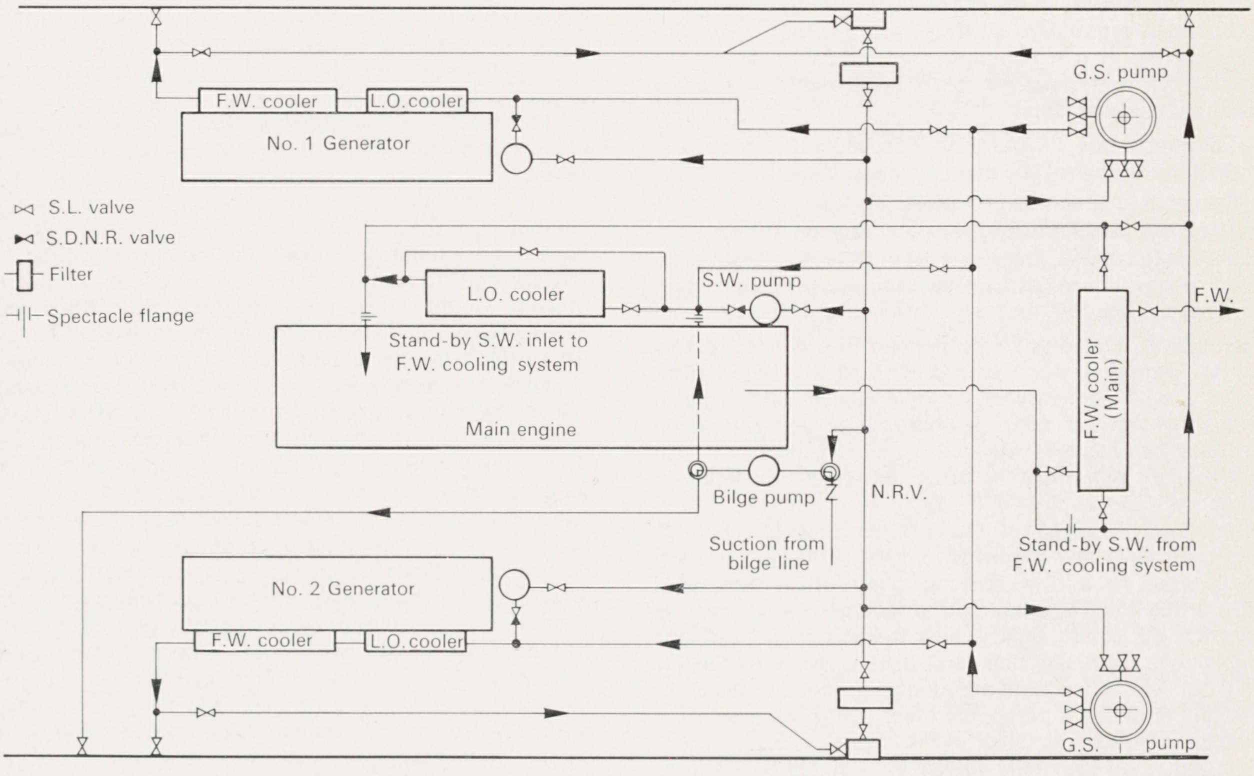


Fig. 20

Cooling Water System

a gap between the bars of 25 mm, which is also indicated in BS MA 18 'Salt Water Piping Systems in Ships'.

When steam or compressed air connections are fitted to sea inlet valves or stools for clearing purposes, it is desirable that the pressure in these lines should not be too high. A maximum pressure of 0.7 N/mm^2 (7 kg/cm^2) should be sufficient for the purpose and within this pressure there will be no need for extra heavy ship's side fittings.

Sometimes the clearing of sea inlets is effected by discharging water through them at fairly high pressure. If permanent pipes are provided no special precautions are necessary, but if hoses are used the pressure water inlet valves on the sea connections should be of the S.D.N.R. type and fitted with a cap suitable for the type of hose connection employed.

4.9.1 Rubber Expansion Pieces

It is becoming common practice on larger vessels to fit fabric reinforced rubber expansion pieces at suitable points in the cooling water inlet and discharge lines. These fittings have reached a high degree of reliability and have proved their worth in minimizing the effects of vibration and the stresses caused by changes of temperature in the relatively large and heavy pipes of the cooling water system.

Attention is, however, drawn to Chapter 13, 2.8.3 which requires the provision of adequate protective guards which will effectively enclose but not interfere with the action of the expansion piece where failure could result in flooding of the machinery space.

4.10 Lubricating Oil Systems

4.10.1 Standby Pumps

As in the case of cooling water systems, the question of a standby pump is an important consideration.

In steamers and large motorships it is customary for independent lubricating oil pumps to be fitted, and the provision of a standby pump can be taken almost for granted. It is on small motorships such as coasters, tugs, etc., with engines having attached pumps, that difficulties arise. The Rules require a standby pump to be provided where the following conditions apply:—

(i) The lubricating oil pump is independently driven and the total output of the main engine(s) exceeds 370 kW.

(ii) One main engine with a built-in lubricating oil pump is fitted and the output of the engine exceeds 370 kW.

(iii) Two or more main engines each with a built-in lubricating oil pump are fitted and the output of each engine exceeds 370 kW.

The standby pump is to be permanently connected and ready for immediate use. An exception to this requirement may be given in the case of multiple engine units (type iii installations) when a complete spare pump unit carried on board may be accepted, provided the arrangements are such that the spare pump can be easily and readily installed in accordance with Chapter 14, 8.1.2.

A common arrangement on diesel engines of moderate power is to have two engine-driven pumps which normally work in series, i.e. a lift or scavenge pump which draws used oil from the engine sump and discharges to a separate lubricating oil service tank, whilst the second, or pressure pump, draws from this tank and discharges to the engine supply rail. The connections are so arranged that, in the event of the failure of either pump, the other pump can draw from the sump and discharge direct to the engine system.

The pumps are generally driven by a single eccentric or single toothed wheel on the crankshaft and, accordingly, they are not entirely independent. Such arrangements have been accepted for many years and appear to be justified by service experience.

The requirements regarding a standby pump are also applicable to engines which are fitted with reverse reduction gears and oil-operated couplings. Some manufacturers provide an independent standby pump which can serve either the engine or the reduction gear, as may be required.

In large single engine ships, having independent pumps, there should be one standby pump irrespective of the number of working pumps. If one of the working pumps supplies the lubrication service and the other working pump deals with the piston cooling oil, one standby pump, which can be connected to either service, is acceptable. This is illustrated in Figure 21.

Independently operated lubricating oil pumps are to be capable of being stopped from outside the compartment in which they are situated. Further, outlet valves on lubricating oil deep tanks, which are normally open in service, are to be controlled in the same way as those on oil fuel tanks, and pumps of rotary type are to be fitted with non-return valves on the discharge side.

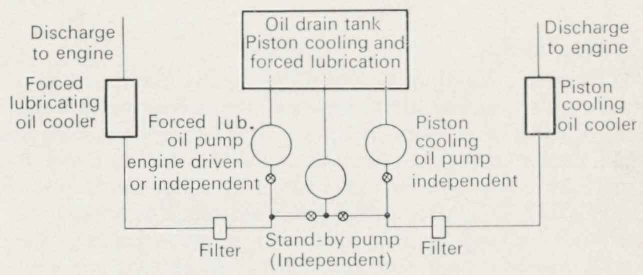


FIG. 21

Lubricating Oil Standby Pump

4.10.2 Emergency Lubricating Oil Supply in Turbine Ships

Turbine ships are required by the Rules to have an emergency supply of lubricating oil for use in the event of a stoppage of the working pump(s). This is generally effected by arranging an automatic gravity supply which comes into operation when the pressure in the lubricating oil system falls below that due to the head of the gravity tank.

The capacity of the gravity tank should be sufficient for not less than 6 mins. normal operation as required by Chapter 14, 8.5.2.

If it is not desired to fit a gravity tank, an acceptable alternative is the provision of a standby pump deriving its power from a different source from that of the working pump, and arranged to come into operation automatically when the pressure in the lubricating oil system falls below a predetermined point. The alarm device mentioned in Chapter 14, 8.4.1 should, of course, be fitted.

In some turbine installations it is not uncommon for a lubricating oil pump driven from the main gear box to be fitted in conjunction with the main lubricating oil system. This pump would augment the gravity supply in the event of failure of the main lubricating oil pumps.

Figure 22 shows a typical lubricating oil system for a turbine unit incorporating a pump driven from the main gearing as indicated in the previous paragraph. With this arrangement, the combined gravity tank and gear unit would possibly supply sufficient oil for bearing protection until the turbines come to rest, which during normal run out after a black-out may take about 20–30 mins. With such an arrangement it is possible that a complete run down may be accomplished without any, or only limited, damage to the bearings.

4.10.3 Sounding arrangements for Lubricating Oil Tanks

Two or three lubricating oil service and storage tanks, having considerable capacity, may be located in the upper part of the machinery space. These tanks are as potentially

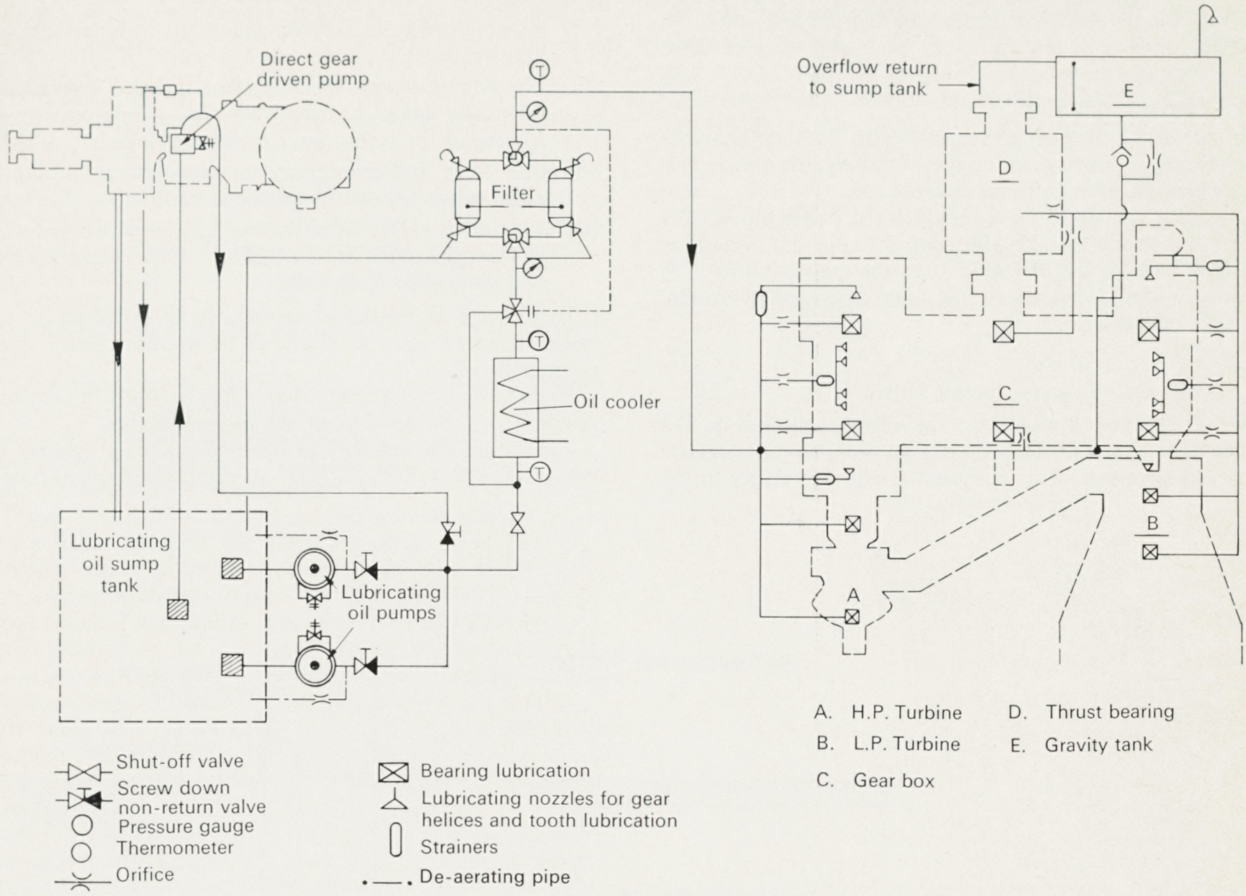


FIG. 22

Turbine Lubricating Oil System

dangerous as the oil fuel service tanks and, therefore, air and sounding arrangements for lubricating oil tanks should be similar to those for oil fuel service tanks.

4.10.4 Separation of Oil Fuel and Lubricating Oil Tanks

Lubricating oil tanks are to be separated from tanks carrying oil fuel by cofferdams as required by Part 3, 5.7.1.

4.10.5 Crankcase Vent Pipes

It is sometimes proposed to fit a vent pipe to the engine crankcase. If, however, an explosion took place in the crankcase there could be a rapid re-entry of fresh air via this pipe, possibly producing a severe secondary explosion. For this reason, when a crankcase vent pipe is fitted it is considered that it should:—

(i) have a cross-sectional area which is small in relation to the area of the explosion relief valves; preferably the pipe should not exceed 50 mm bore, or:

(ii) have a non-return or other suitable device fitted in the line, which will effectively restrict the flow of air back to the crankcase.

4.11 Compressed Air Systems

4.11.1 Number and Capacity of Air Compressors

The Rules require two air compressors to be provided for starting and manœuvring purposes, having a total capacity sufficient for the requirements of the engines. This capacity should permit the charging of air receivers in a reasonable time and is usually determined by experience.

It is desirable that the air compressors should be independently driven, but this is not insisted upon, and one of the compressors may be driven by the main engine.

4.11.2 Number of Air Receivers

There are no Rule requirements regarding the number of air receivers which should be provided. In practice, it is usual to fit not less than two receivers, but there are cases in which only one receiver is provided per ship. In the case of passenger ships, however, not less than two air receivers are to be provided.

4.11.3 Safety Devices

In view of the importance of these devices, it is considered that every plan of compressed air arrangements should make it clear that each compressor will be fitted with a relief valve and that each air receiver be fitted with a relief valve or fusible plug.

When dealing with plans of compressed air systems particular attention is drawn to the following requirements in Chapter 2, 7.

Starting air from compressors is to be led direct to the starting air receivers. The starting air from the receivers to the main and auxiliary engines is to be entirely separate from the compressor discharge piping.

An isolating valve of non-return type is to be fitted at the starting connection to each engine, but this requirement is not applicable in the event of the main and/or auxiliary engines being started by an air motor.

Oil and water separators are to be fitted in the discharge line between the air compressor discharge and the air receiver(s).

4.11.4 **Starting from Cold**

It is necessary for the arrangements to be such that the initial charge of starting air or the initial electric power can be developed on board without external aid.

There are a variety of ways in which the prime movers for the air compressors can be started from cold but, whatever form they take, it is desirable that the power should be developed by hand operation, e.g. hand operated hydraulic/ pneumatic inertia starters.

4.11.5 **Pneumatic Remote Control Valves**

It is sometimes proposed that the valves, required by the Rules to be capable of being closed from deck, have pneumatic closing arrangements. This has been accepted, subject to the following conditions being complied with:—

(i) An emergency air receiver is located outside the machinery space.

(ii) The emergency air receiver is maintained fully charged from the main air receivers via a non-return valve located at the emergency air receiver inlet.

(iii) The main and emergency air receivers are fitted with relief valves (fusible plugs not to be fitted).

(iv) The outlet valves from the main air receivers are locked in the open position if not fitted with extended spindle and controlled from deck.

In the case of passenger ships, a hand operated air compressor should also be provided in the emergency control compartment.

Figure 23 shows a general arrangement of a 'Compressed Air System', incorporating these requirements.

In all cases the capacity of the emergency air receiver is to be sufficient to operate all the valves without replenishment.

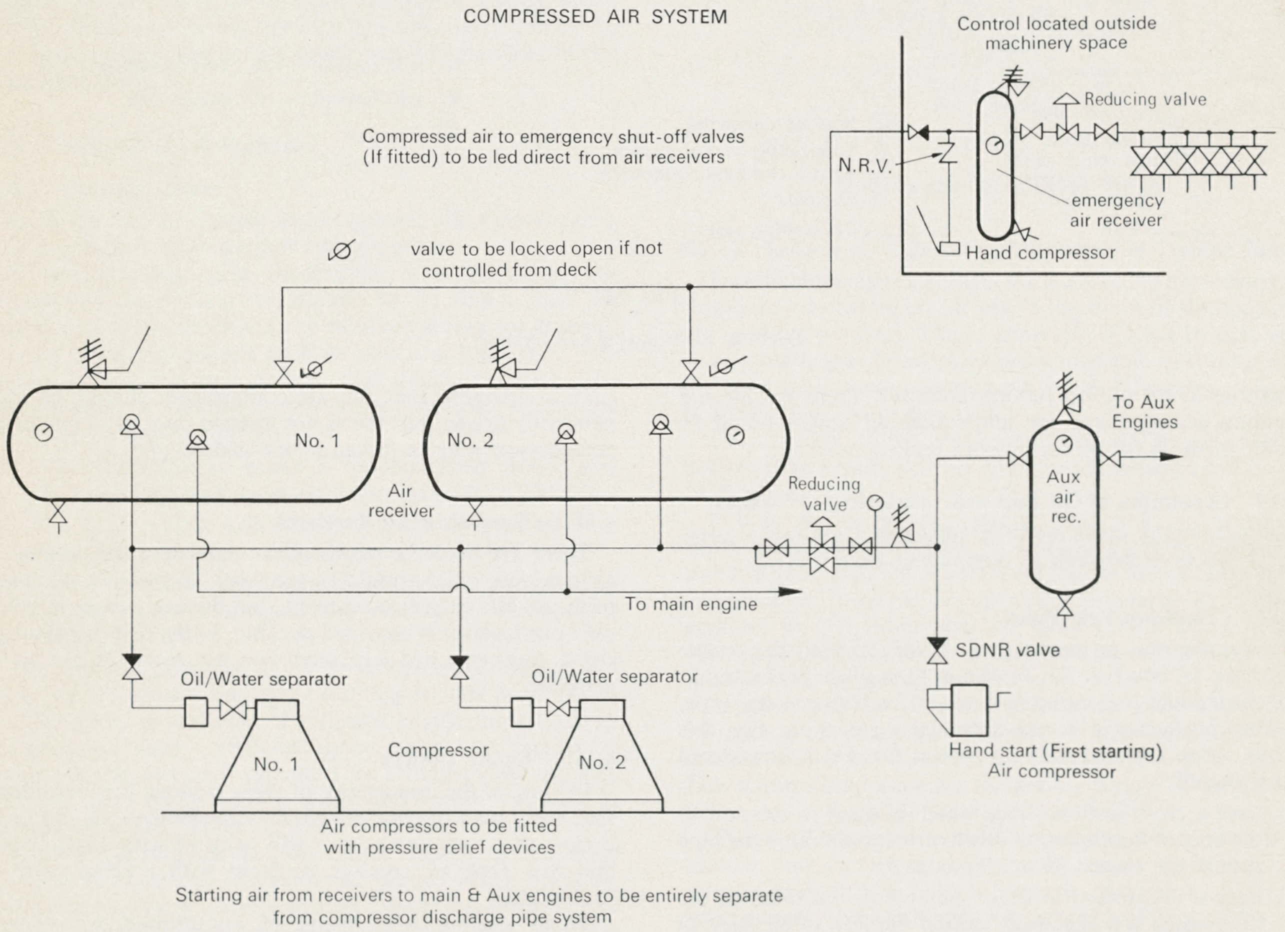


FIG. 23

Compressed Air System

5 PIPING SYSTEMS FOR OIL AND CHEMICAL TANKERS

5.1 Oil Tankers

5.1.1 Cargo Tank Pumping Arrangements

Plans of the cargo pumping arrangements for oil tankers do not generally call for much comment. In detail there is a fair amount of uniformity, but in the lay-out of the cargo oil lines in the tanks there is considerable variation, depending upon the owners' practice and the particular trade for which the vessel is required, i.e. whether the ship is to carry homogeneous or composite cargoes (crude or product carrier).

It is fairly common to regard hydraulic testing of pipe lines as a safe procedure, but in very large tankers there is a hidden danger.

Pipes connecting the lines in the tanks to the lines on deck can act as accumulators so that pressure in the line is not immediately dissipated by a small leak. In view of this hidden danger it is suggested that, as far as possible, these risers should be isolated when testing the tanks.

In large vessels it is usual to provide only one cargo pump room situated between the aftermost cargo tanks and the machinery space. In order to speed up the rate of discharge high capacity centrifugal pumps are fitted in place of reciprocating pumps. These pumps are driven by turbines or electric motors situated in the machinery space, the driving shafts passing through the bulkhead separating the compartments.

The scantlings of many of these large tankers are approved on the basis that certain tanks will be empty in the loaded condition. These tanks may be either dry tanks, or water ballast tanks maintained empty in the loaded condition and full in the ballast condition.

Water ballast tanks should be connected to a separate pumping system led to a ballast pump in the cargo pump room. A common arrangement on these ships is to have four identical pumps, three of which are permanently connected to the cargo oil system and one to the ballast system. The ballast piping is not to be connected to the cargo oil piping. However, provision may be made for emergency discharge of water ballast by means of a portable spool connection to a cargo pump and, where this is arranged, a non-return valve is to be fitted in the ballast suction to the cargo pump.

As the ballast line previously referred to necessarily passes through some of the cargo oil tanks, it is sometimes thought this is an infringement of Chapter 15, 2.1.2 but this is not so, as this paragraph refers to ballast pipes and ballast tanks, which are situated outside the range of the cargo oil tanks.

Where a clean ballast pump is located in the cargo pump room, the sea inlet for this pump must be separate and distinct from the sea inlet for the cargo pump.

Chapter 15, 2.6.1 and 2.6.2 requires that where clean ballast lines are led through cargo oil tanks they are to be of steel of substantial thickness, not less than 16 mm thick, and have welded or heavy flanged joints. The number of flanged joints is to be kept to a minimum. Expansion bends not joints are to be fitted in these pipes within the cargo tanks.

5.1.2 Bow or Stern Loading and Discharge Arrangements

When provision is made for bow or stern loading or discharge, provision is to be made for isolating the pipes by means of a removable spool piece at the forecastle or after deck house front. A blank is also to be provided at the end of the pipe irrespective of the number and types of valves in the line.

5.1.3 Expansion Joints in Cargo Oil Lines

Provision for expansion in cargo oil lines, due to changes of temperature, movement of the ship, etc., may be made in a variety of ways. It is now fairly general, however, to use joints or couplings of the types shown in Figures 24 and 25, which are able to accommodate the effects of expansion and contraction. It should be noted from the latter sketch that the pipes have no groove or shoulder to prevent them pulling out of the joint when the line is subjected to pressure, Figure 25. Therefore, when this type of joint is employed it is necessary to provide substantial anchoring arrangements for the pipes.

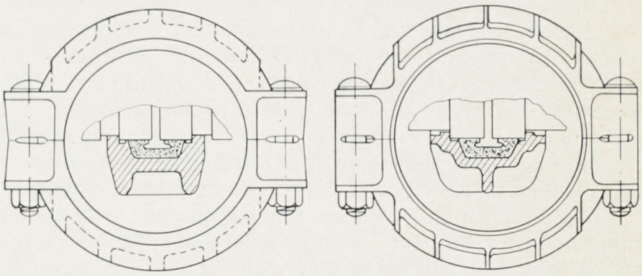


FIG. 24

Expansion Joint

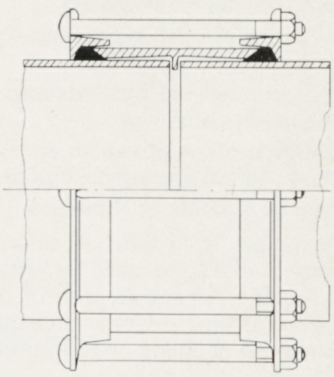


FIG. 25

Expansion Joint

Bellows type expansion pieces made of thin stainless steel are now sometimes used, and Figure 26 is a sketch of one of these fittings. Bellows pieces are to be of approved material, and adequately protected externally against mechanical damage.

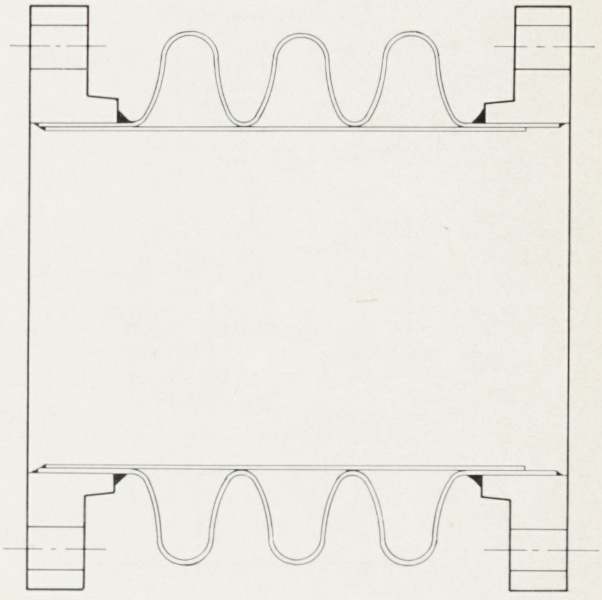


FIG. 26

Bellows Unit

The bellows pieces are to be installed in such a manner that they are not used to correct mis-alignment of the pipes and any lateral movement or over-extension of the bellows is to be prevented.

5.1.4 Gas-tight Glands

When the prime movers for the cargo pumps are situated in the machinery space, the Rules require that the shaft which passes through the pump room bulkhead is to be fitted with a gastight gland having efficient means of lubrication. It is not necessary for plans of these glands to be approved, but nevertheless, a large number of designs have been forwarded for consideration. Some consist of a few turns of packing on each side of a lantern ring, while others are more elaborate.

Grease lubricated glands are not looked upon with favour since they rely too much on operational discipline. Unless the gland generates sufficient heat to melt the grease there could be a ring of grease on the face of the gland and still permit a clear passage for gas.

5.1.5 Cargo Tank Venting Arrangements

Chapter 15, 4.1.3 requires that cargo tank venting arrangements are to provide:—

(i) Pressure/vacuum release of small volumes of vapour/air mixtures during normal voyage.

(ii) Venting of large volumes of vapour/air mixtures during cargo handling and gas freeing operations.

These systems may be separate or combined.

Where the vent pipes from different tanks are led to a common main, provision is to be made for isolating each tank from the common main. Means are also to be provided to prevent any tank from being subjected to excessive pressure or vacuum during cargo handling or ballast operations.

Pressure/vacuum valves where fitted are normally set at a positive pressure of not more than 0.02 N/mm^2 (0.2 kg/cm^2) above atmospheric pressure, and not more than 0.007 N/mm^2 (0.007 kg/cm^2) below atmospheric pressure.

5.1.6 Location of Cargo Tank Vents

In accordance with Chapter 15, 4.5.3, pressure/vacuum valve outlets are to be located not less than 1.8 m above the deck. Chapter 15, 4.5.1 requires that the height of open vents which permit a free flow of vapour/air mixture to be not less than 4 m above the weather deck, or within 4 m of the fore and aft gangway, where fitted. The vent pipes are to be located not less than 10 m from the nearest air intake, or openings to accommodation, or enclosed working areas, or any possible sources of ignition, Figure 27.

Vent pipes incorporating high velocity heads which are arranged to discharge the vapour/air mixture at a velocity of not less than 30 m/second, may be accepted in lieu of the open vent pipes.

The height of the outlets from such high velocity heads is to be not less than 1.8 m above the deck in accordance with Chapter 15, 4.5.3, and these may or may not incorporate the pressure/vacuum valve required.

Figure 28 shows a typical high velocity vent head incorporating the pressure/vacuum valve.

5.1.7 Temperature of Pipes in Pump Rooms and other Hazardous Areas

As indicated in Chapter 15, 1.5.1, the temperature of steam or other fluid in pipes passing through spaces likely to contain hydro-carbon or other explosive vapours is not to exceed 220°C.

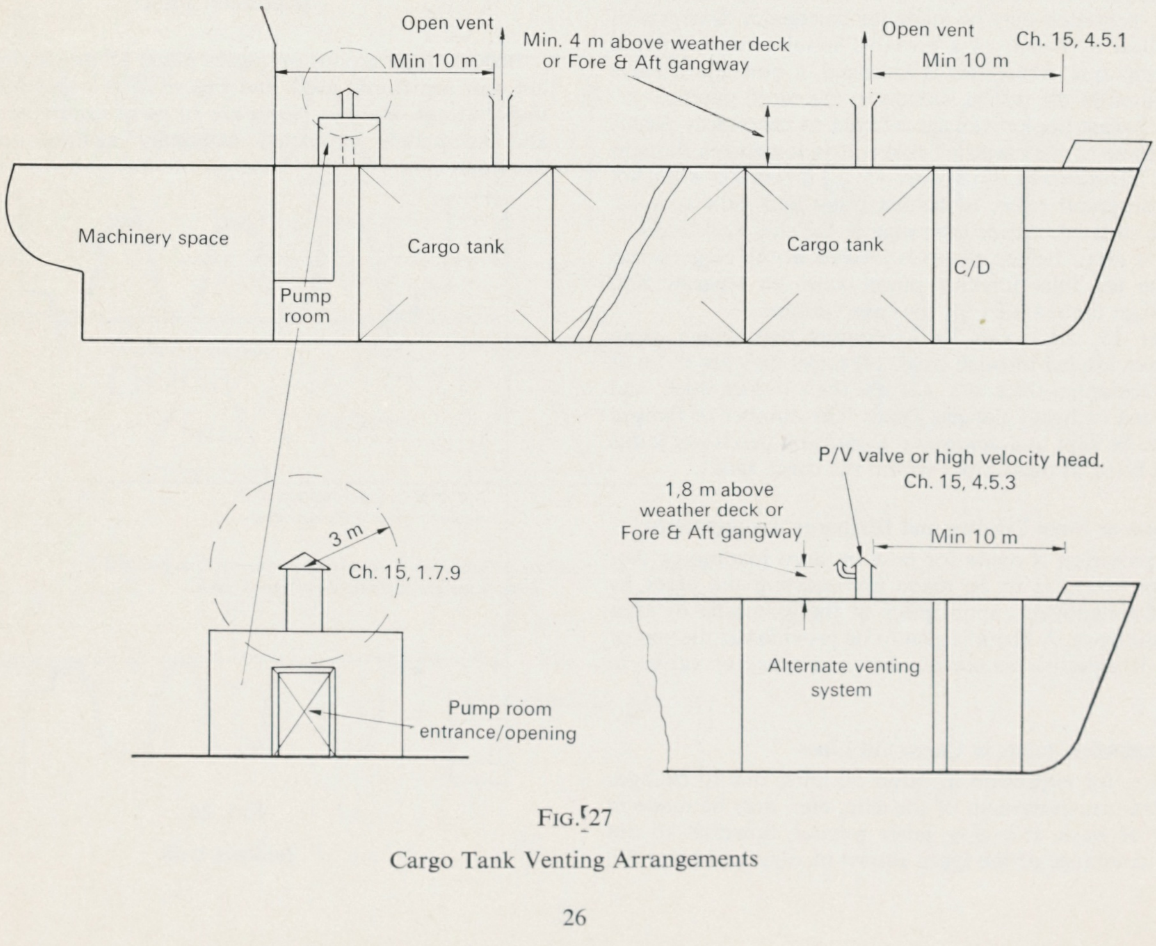


FIG. 27

Cargo Tank Venting Arrangements

5.1.8 **Cargo Tank Sounding Arrangements**

Chapter 15, 5.1.1 requires that sounding pipes or other approved devices be provided for ascertaining the liquid level in the tanks.

Sounding devices which permit a limited amount of vapour to escape may be accepted. Ullage openings may be accepted as a reserve means of sounding, but any device which permits the escape of vapour is not to be located in an enclosed space.

5.1.9 **Pumping Arrangements in Forward Pump Rooms**

In most tankers, the arrangement of the forward pump room, if fitted, is of fairly standard pattern, but sometimes there is need for improvement and Figure 29 is an example of acceptable forward pumping arrangements.

It is common practice to fit a diesel-driven emergency fire pump in the forward auxiliary bilge and ballast pump room, and this is in order provided that the compartment is completely separated from the cargo tanks by a cofferdam.

It is considered advisable that the emergency fire pump should have a separate sea suction valve connection as indicated on the diagram. Further, the exhaust gases from the diesel engine should be discharged through an efficient spark arrester to a safe position well clear of the cargo tanks, and the pump room should be well ventilated.

There is always the possibility of the forward cargo hold being used for the carriage of petroleum products and, therefore, the plating of the trunkway giving access to the pump room should be gastight in way of the hold.

5.1.10 **Thermal Oil Heating Systems**

The normal arrangement of cargo oil heating utilizes low pressure steam from the main/auxiliary boilers, but an alternative to this may be a thermal oil heating system. In this system, the normal heating coils are fitted in the tanks but the coils are circulated with hot oil at low pressure instead of steam.

The circulating oil has a high flash point and is heated by means of a coil type boiler which is fired in the normal way by oil fuel.

Advantages of the system are that higher temperatures can be obtained than that with saturated steam at normal pressures, and since the circulating pressure of the thermal oil is low, thin walled tubes may be employed.

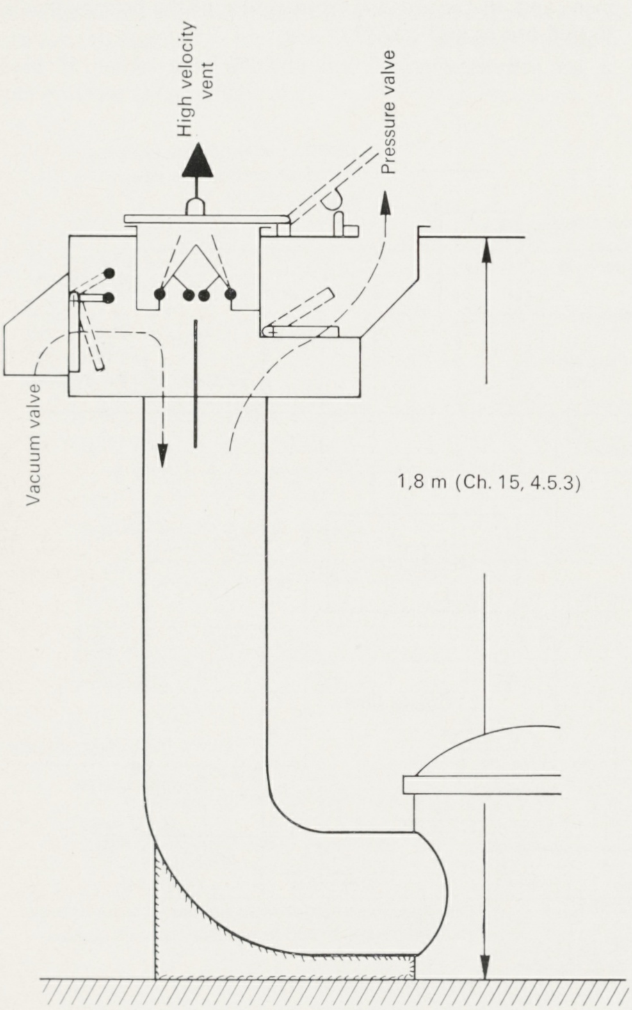


FIG. 28

High Velocity Vent Head

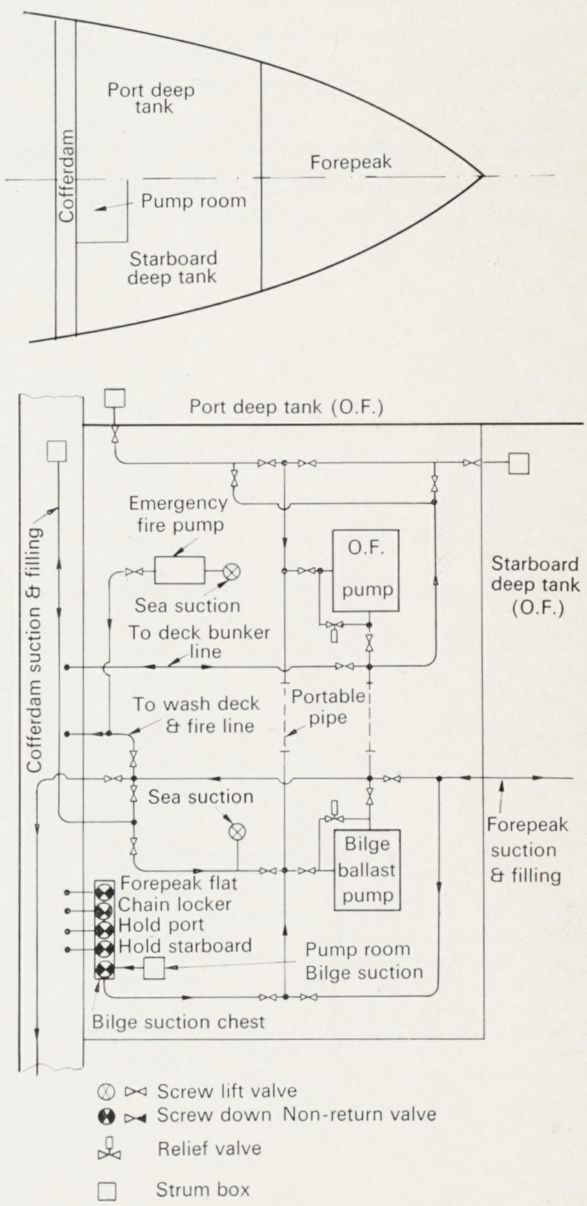


FIG. 29

Pumping Arrangements in Forward P/P Room

It will be appreciated that with this system of heating special precautions must be taken to safeguard the thermal oil circulation system. In this respect the following requirements should be complied with:—

(i) The thermal oil header tank should be fitted with high and low level alarms, and located some distance above the highest part of the heating installation.

(ii) The expansion tank air pipe should be led to a safe position on the open deck and fitted with a gauze cover.

(iii) The outlet valves should be fitted direct to the de-aerating and expansion tanks. The valves should be capable of being controlled from outside the compartment in which the tanks are situated.

(iv) A standby thermal oil circulating pump should be provided. The pumps should be capable of being stopped from outside the compartment in which they are situated, and provided with effective relief valves in closed circuit.

(v) Suitable strainers should be fitted on the suction side of the thermal oil pumps to filter out any carbonized oil.

(vi) Air release pipes should be fitted in the thermal oil system with discharges to the header tank, or fitted with self-closing valves and led to safe positions.

(vii) So far as is practicable, flanged joints or other approved type couplings should be used throughout the system.

(viii) The thermal piping should comply with the requirements of the relevant paragraph of the Rules.

(ix) A drain cock or valve should be fitted to the bottom of the oil heater combustion chamber for draining purposes.

(x) The flash point of the thermal oil should not be less than 60°C.

(xi) A thermostatic control or cut-out actuated by the circulating oil temperature, failure of circulating pump and flame out, should be incorporated in the oil heating burner system.

(xii) All drain valves should be of the self-closing type.

Further, it is recommended that a re-circulating valve should be provided and so arranged that, when first lighting up the oil heating units, the thermal oil can be returned to the heater without having to pass through the heating coils in the cargo oil tanks.

The recommendation to provide a standby circulating pump is of particular importance where the cargo is of such a nature that it would solidify at normal ambient temperatures.

In view of the dangerous situation which could arise in the event of contamination of the thermal oil with low flash cargo oil, it is considered that a permanent notice should be displayed in a prominent position in the engine room and on deck, stating that the thermal oil system should remain under pressure, except when the ship is either carrying cargo having a flash point above 60°C or the cargo tanks are empty and gas free, and that the thermal oil system will be pressurized before low flash oil is loaded. Figure 30 is a suggested arrangement and, in general, the temperature of the heating medium should not exceed 220°C.

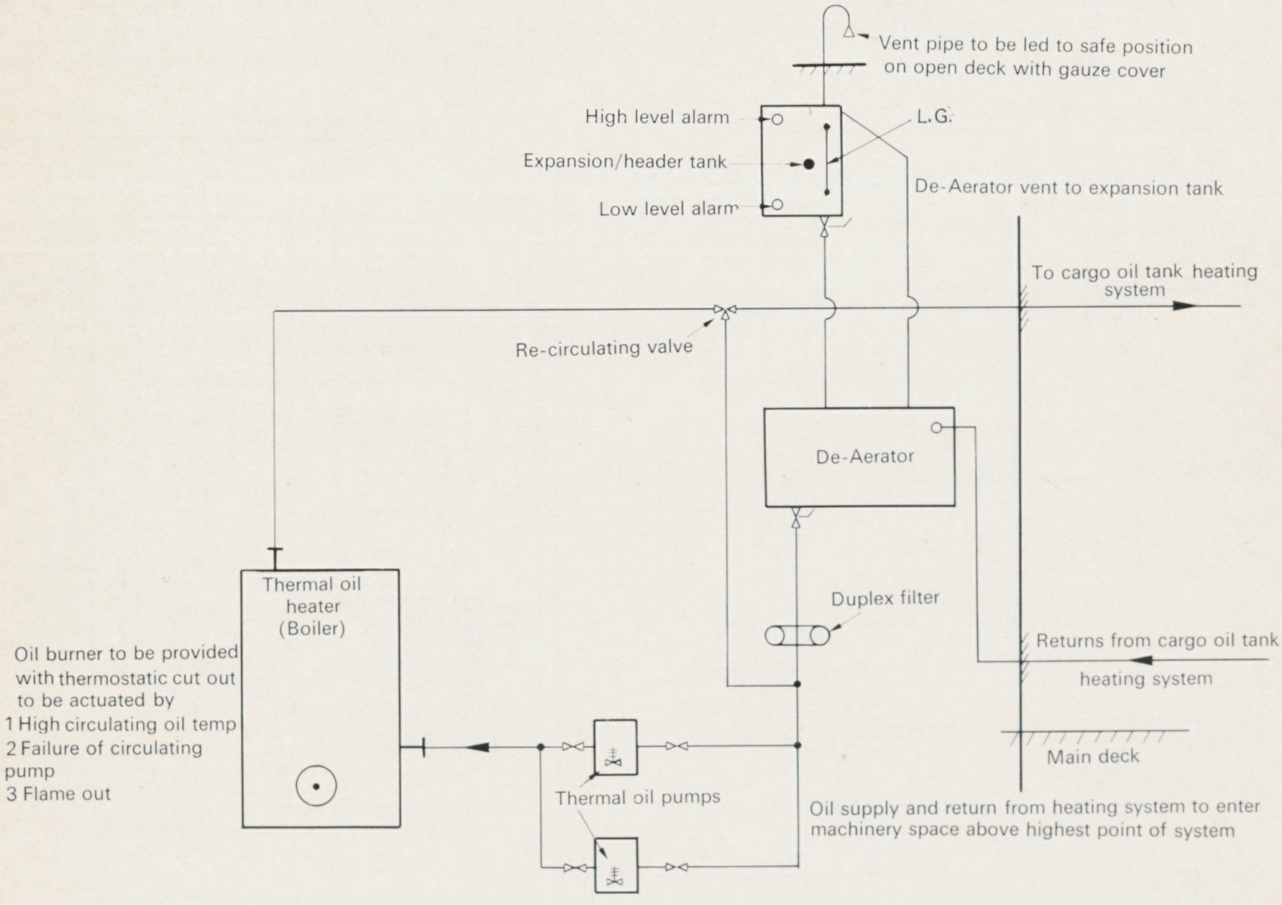


FIG. 30

Thermal Heating System

5.2 Chemical Tankers

5.2.1 Chemical Tanker Systems

Chemical cargoes are normally referred to as Type 'A', 'B' or 'C' and are shown in the appropriate tables of cargoes as listed in Chapter 15, Tables 15.1.1 ('A' Type), 15.1.2 ('B' Type) and 15.1.3 ('C' Type).

Cargo Type 'A' ships are primarily intended for the carriage of Type 'A' chemical cargoes, but may carry Type 'B' and 'C' cargoes.

Cargo Type 'B' ships are primarily intended for the carriage of Type 'B' chemical cargoes but may also carry Type 'C' but not Type 'A' cargoes.

Cargo Type 'C' ships are primarily intended for the carriage of Type 'C' cargoes only but may also carry cargo oil, the pumping arrangements for these systems being the same. The following requirements are in addition to, or supersede, the relevant Rules for Oil Tankers.

Piping systems are to be suitable for the maximum pressure to which they can be subjected, but in no case less than 1.03 N/mm^2 (10.5 kg/cm^2) for the chemical Type 'A' or 'B' cargoes.

For Type 'A' and 'B' chemical cargoes, Chapter 15, 2.2.2 requires that the pump room bilge system be capable of being operated from outside the pump room, above the weather deck, as well as in the pump room.

5.2.2 Clean Ballast Lines in Way of Cargo Tanks

Arrangements whereby ballast lines pass through cargo oil tanks are not acceptable for Type 'A' or 'B' chemical cargoes. Figure 31 shows a simplified pumping arrangement for a Type 'A' class cargo chemical carrier.

5.2.3 Cargo Tank Venting

The height of the open vent outlet for chemical tankers is to be not less than 4 m above the weather deck, or within 4 m of the fore and aft gangway if fitted. The height may be reduced to 2.5 m if the vent pipe is fitted with an approved high velocity vent head. The vapour outlets are to be arranged not less than 10 m from the nearest air intake or opening to accommodation, enclosed work areas or possible source of ignition.

For Type 'C' class cargoes the height of the outlet from the high velocity head may be reduced to 1.8 m.

For certain chemical cargoes, as indicated in Table 15.1.1 and Table 15.1.2, the height of the vapour outlet is to be not less than 6 m or $\frac{1}{3}$ of the breadth of ship, whichever is the greater, above the weather deck or fore and aft gangway. Further, the distance from any source of hazard is to be not less than 15 m. *See* Figure 32.

5.2.4 Sounding Devices

Each cargo tank is to be fitted with an approved means of ascertaining the level of the liquid in the tanks, which may be:—

(i) restricted sounding device or

(ii) closed sounding device according to the chemical cargo concerned.

In addition, it may be necessary in the case of cargoes as indicated in Table 15.1.1 for high level alarms to be provided in accordance with Chapter 15, 5.4.1 and 5.5.1.

Ullage openings are not accepted as reserve means of sounding for Type 'A' cargo or Type 'B' cargo chemical tankers.

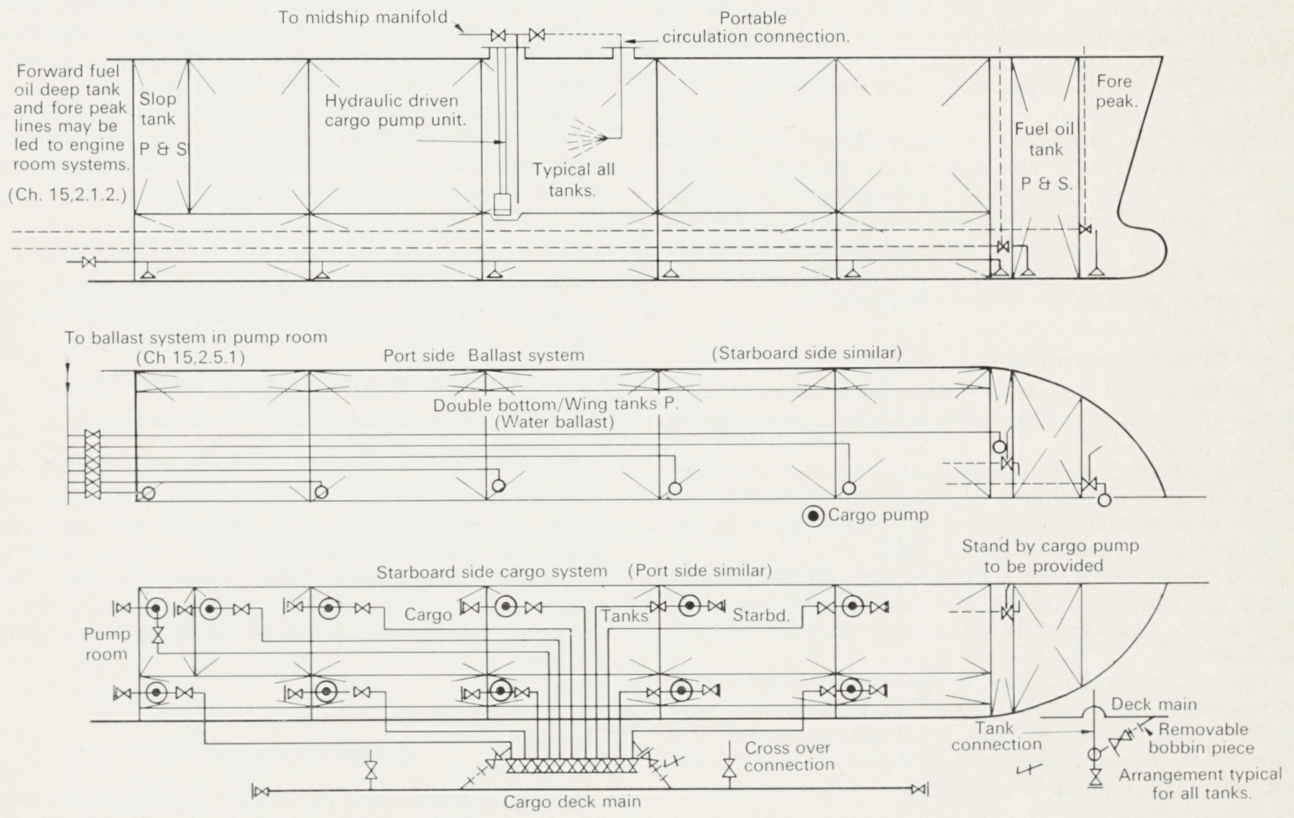


FIG. 31

Chemical Tanker Pumping Arrangements

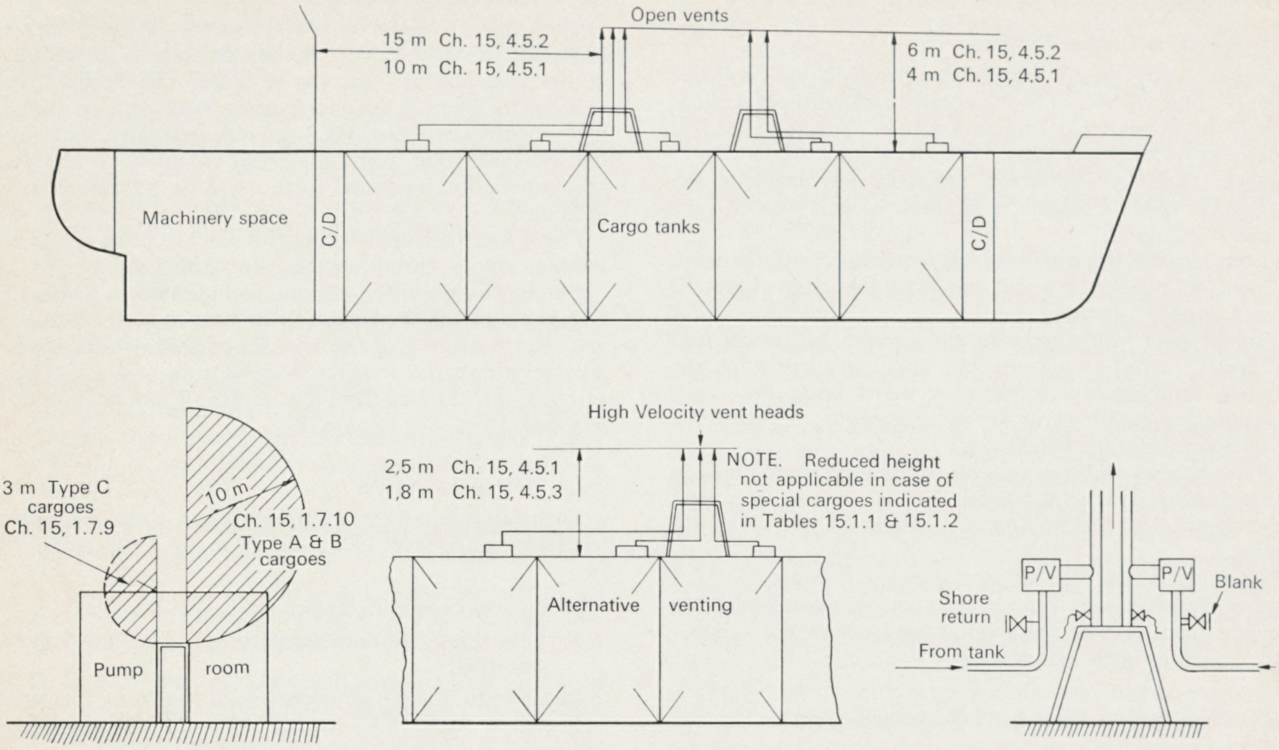


FIG. 32

Chemical Tanker Venting Arrangements

5.2.5 **Inert Gas Systems**

Where provision is made for inerting cargo tanks as required by Chapter 15, 8.1, the system, if provided from 'flue gas', is to comply with requirements for an inert gas system as later described, and due regard must be paid to the segregation of cargoes.

Where inert gas is required for spaces adjacent to cargo oil tanks only or 'padding' the cargo tanks, inert gas storage vessels are acceptable, subject to the capacity of the storage vessels being sufficient to deal with any normal anticipated losses during the voyage. This latter arrangement would not be considered for I.G. notation. In all cases the inert gas is to be compatible with the cargo to be carried.

5.2.6 **Cargo Heating Systems**

The heating medium is to be compatible with the cargo to be heated, and where a cargo is water-reactive, steam heating should not be used.

Where a thermal oil heating system is provided, the arrangements are to be as indicated in paragraph 5.1.10—Thermal Oil Heating Systems. In general, the temperature of the heating medium should not exceed 220°C.

Provision is to be made for blanking off the heating system in circumstances where the cargo does not require to be heated, or where portable heating coils are removed from the tanks.

When steam heating is used for heating toxic cargoes the heating return lines should be led to an observation tank usually located on the open deck, but if the observation tank is located in the machinery space, it should be of the closed type with an air pipe led to a safe space on the open deck.

5.2.7 **Segregation of Cargoes**

Segregation of tanks carrying incompatible cargoes is covered in Chapter 15, 3.6.1–3.6.2.

With regard to piping systems which serve tanks carrying incompatible cargoes, isolation of the piping system is to be made by means of removable pipe lengths and the fitting of blank flanges. Single or double shut-off valves, or spectacle blank flanges are not acceptable for this purpose.

Further, cargo piping is not to be led through other tanks containing incompatible cargoes. If it is impracticable to route the piping in order to comply with the above, the pipes should be led through a pipe tunnel or duct.

5.2.8 **Ventilation of Pump Rooms**

The below-deck pump room ventilation should be of the mechanical extraction type, having air changes as indicated below:

For ships Type 'A' Cargoes — 45 changes per hour

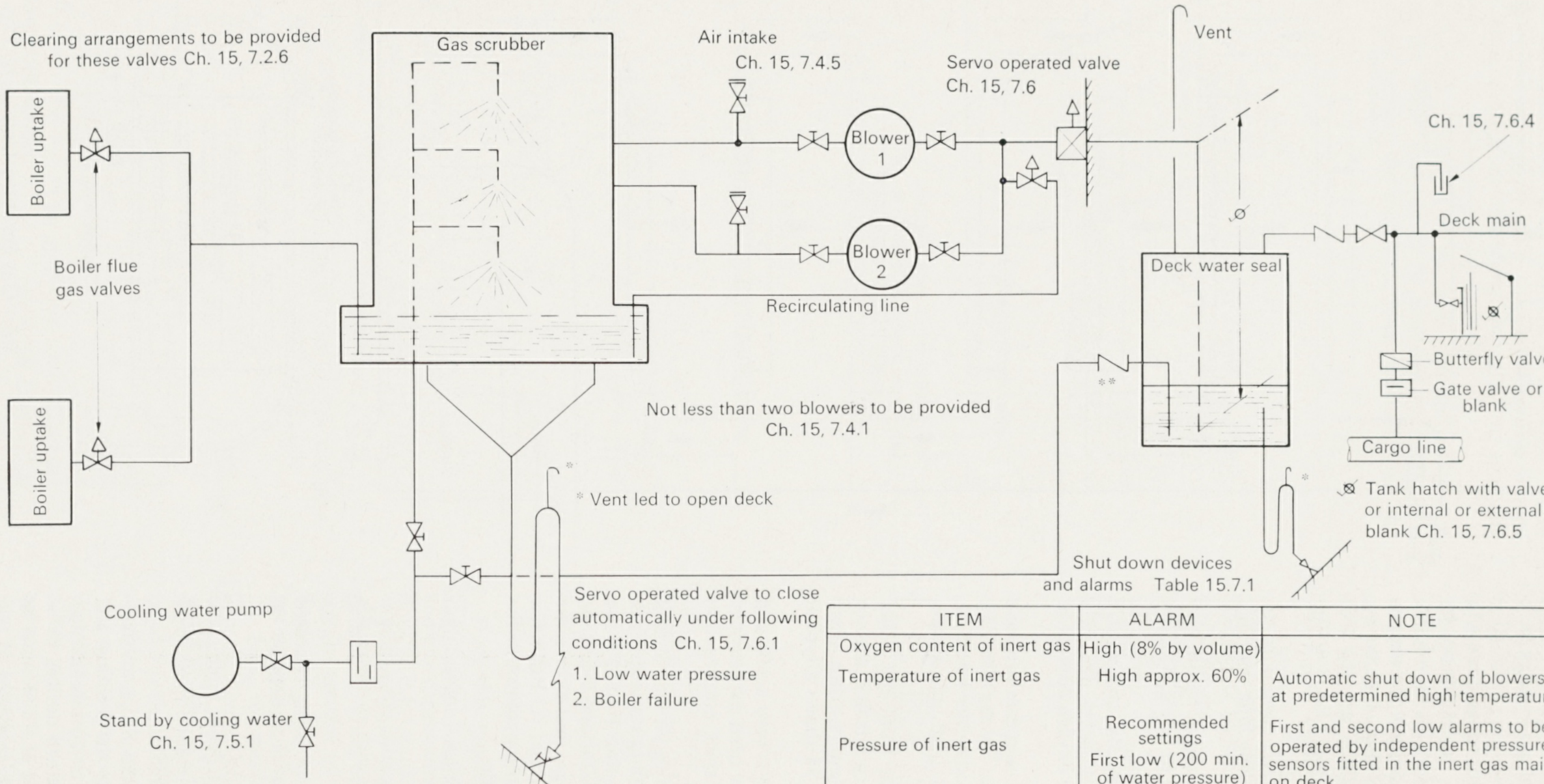
For ships Type 'B' Cargoes — 30 changes per hour

For ships Type 'C' Cargoes — 20 changes per hour

Other spaces adjacent to cargo tanks containing cargo piping and valves which are not normally required to have access for operational purposes, are to be provided with permanent venting capable of eight changes of air per hour or, alternatively, to be fitted with means for attaching portable mechanical equipment capable of supplying 15 air changes per hour.

6 INERT GAS SYSTEMS

In order to comply with the Rules for fire prevention, Part 6, Chapter 4, 20.2.2 requires that tankers over 100 000 tonnes dwt and crude oil combination carriers over 50 000 tonnes dwt are to be provided with inert gas systems. A number of government administrations have similar regulations.



Arrangements to be such that soot blowers are not operated when corresponding flue gas valve is open. Ch. 15, 7.2.5 ⌀ Height of inert gas inlet pipe and column of water in seal to be sufficient to give a head of 8 ft. against back pressure from cargo tanks. Ch. 15, 7.6.3
N.R. valve to be fitted in water supply line adjacent to deck seal. Open end pipe to be submerged under all conditions

INSTRUMENTS TO BE PROVIDED Ch. 15,7.9.1

1. Oxygen content indicator and recorder
2. Temperature indicator
3. Pressure indicator and recorder

ITEM	ALARM	NOTE
Oxygen content of inert gas	High (8% by volume)	—
Temperature of inert gas	High approx. 60%	Automatic shut down of blowers at predetermined high temperature
Pressure of inert gas	Recommended settings First low (200 min. of water pressure)	First and second low alarms to be operated by independent pressure sensors fitted in the inert gas main on deck.
	Second low(100min. of water pressure)	A notice board is to be fitted at the control position stating that the cargo pumping rate is to be reduced at the second low alarm.
Gas scrubber cooling water pressure or flow	Low	Automatic shut-down of blowers
Deck seal water supply pressure	Low	Alarm to operate at all times when the ship is not gas free
Deck seal water level	Low	Alarm assured for operation when plant is not running.
Automatic control system power supply	Failure	—

FIG. 33

Inert Gas System

It is not a classification requirement that inert gas systems be fitted to tankers of more than 500 tonnes but less than 100 000 tonnes dwt. It is, however, a requirement that if inert gas systems are provided they are to comply with the Rule requirements, Part 6, Chapter 4, 20.2.1.

In the Machinery Plans Department inert gas systems have been dealt with since about 1950.

The purpose of providing inert gas systems for tankers is to endeavour to reduce the possibility of fire/explosion by reducing the oxygen content in the tanks below 8% by volume.

In the past, tanker owners have tried to control the oxygen content of the atmosphere in the cargo and slop tanks during the ballast voyage and tank cleaning, which are the two most dangerous periods, by maintaining a too LEAN or too RICH an atmosphere in the tanks.

In order to obtain an maintain a too LEAN condition, the tanks must be well ventilated before and during tank washing, ballasting and throughout the voyage.

For too RICH systems, the tank is washed before any ventilation is carried out. If the tank is not to be cleaned, but only ballasted, no ventilation is carried out.

It is generally accepted that at some time the atmosphere in the tank must pass through the explosive range. The only method at present to ensure control of the oxygen content at all times is to fit an inert gas system.

In 1972 it was decided that the Rule requirements for these systems should be finalized. Having due regard to the I.M.C.O. proposals, the current Rules now embody the I.M.C.O. requirements. Figure 33 shows a typical inert gas system incorporating the above requirements.

It will be noted that the flue gas taken from the boiler uptake passes through a scrubber unit, there it is first washed and cooled before being admitted to the blowers, from where it is discharged to the deck system. Figure 34 shows a typical scrubber unit.

The effluent discharge from the scrubber is very acidic and abrasive in nature and some difficulty has been experienced with effluent discharge piping, normal steel construction having been found unsatisfactory.

In an effort to reduce the failure rate of this piping, various alternative materials have been used, including stainless steel. Piping constructed of glass reinforced plastics (G.R.P.) has been found to have suitable properties to withstand the acidic and abrasive nature of the effluent discharge, and after some discussion, piping constructed of this material (G.R.P.) has now been accepted for this specific application subject to the following requirements being complied with:

(i) The pipes are to be of substantial thickness (not less than 12.5 mm) and adequately supported.

(ii) The pipe to be fitted with a valve of metallic construction at the shell penetration in conjunction with an automatic non-return valve.

(iii) The shipside valve is to be capable of being operated from a suitable position outside the compartment in which it is situated.

(iv) In the event of failure of the G.R.P. effluent piping, the scrubber cooling water pumps are to be capable of being stopped from outside the machinery space.

Figure 35 shows a suitable overboard discharge arrangement. Special attention is to be given to the jointing and sealing arrangements of the G.R.P. piping to obviate leakage.

The Rules require two approved non-return devices to be provided in the inert gas main on deck, one of which must be a water seal. Figure 36 shows a general arrangement of two types of water seals.

(i) A wet seal in which the inert gas must pass through the water bath.

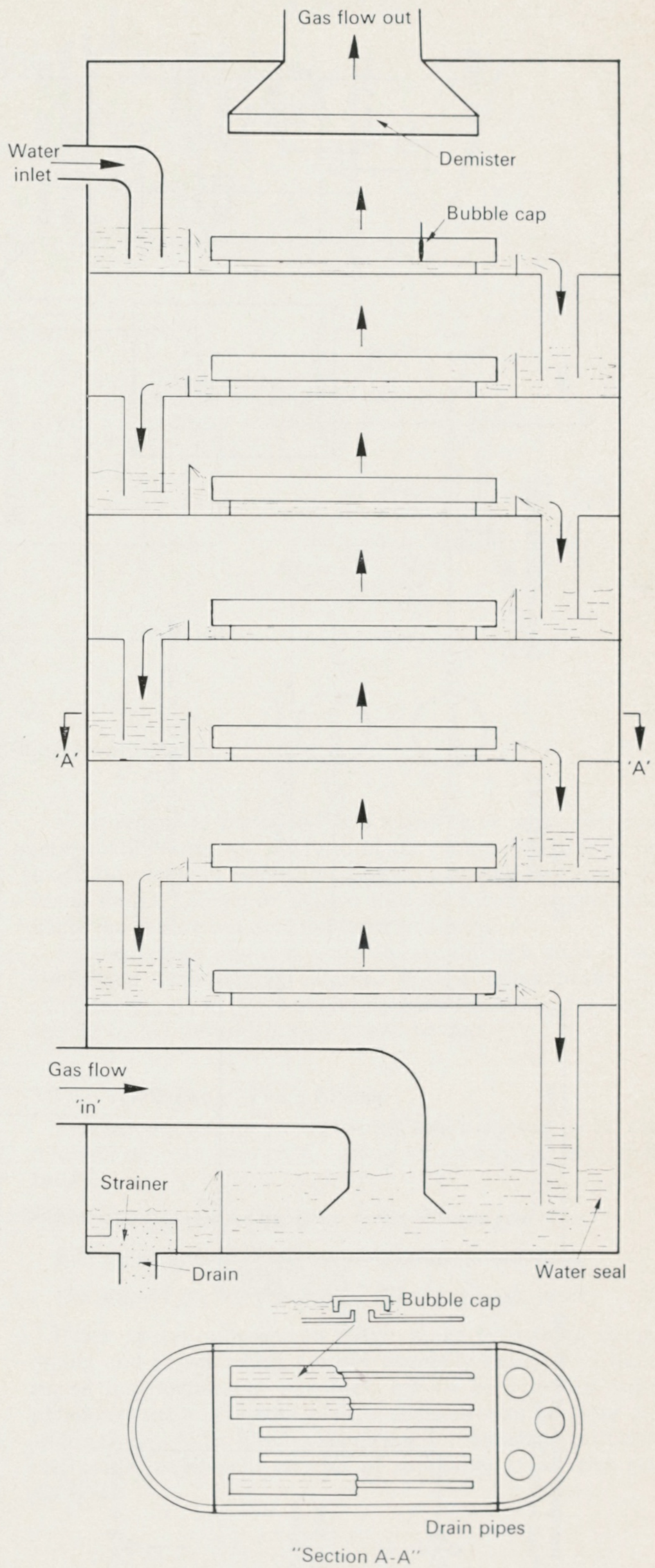


FIG. 34

Inert Gas Scrubber Unit

(ii) A dry seal in which the gas flow acts as a power source for the venturi which creates a vacuum in the section of the seal. This causes a lowering of the water seal in way of the gas supply pipe thus allowing 'dry' gas to pass to the inert gas main. Loss of pressure causes a loss of power at the venturi, with the corresponding loss of vacuum, causing an immediate sealing of the gas inlet pipe.

In both cases the height of the inlet pipe and volume of water in the water seal are to be sufficient to maintain a positive seal against the maximum back pressure from the tank.

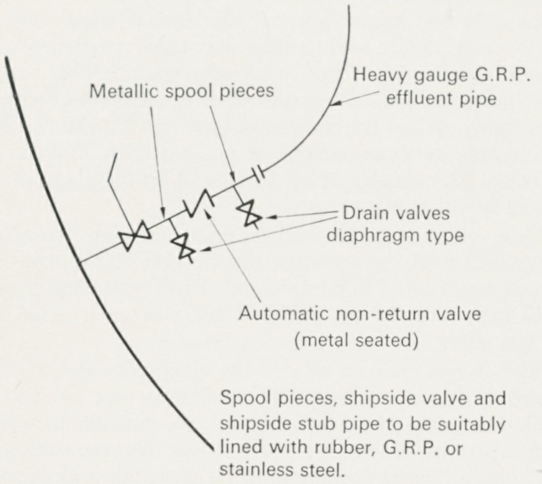


FIG. 35

Inert Gas Effluent Discharge Arrangement

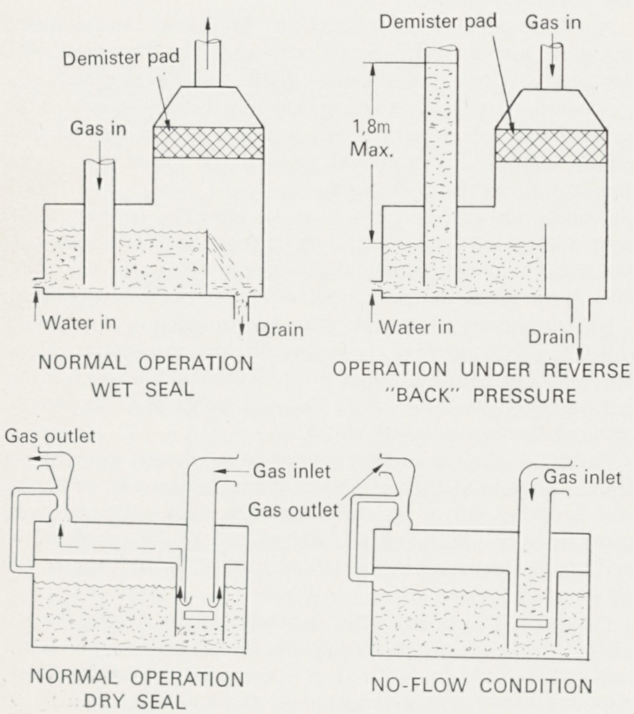


FIG. 36

Typical Water Seals

The Rules require that the maximum oxygen content of the inert gas supply does not exceed 5% by volume and require automatic combustion control at the burner and an audio-visual alarm to operate should the oxygen content exceed 8% by volume.

Hydro-carbon vapour will not burn unless mixed with oxygen, and the amount (percentage) of hydro-carbon vapour which, when mixed with air, will result in a flammable/explosive mixture lies, in general, between two limits. These limits may vary with the type of crude oil but are generally accepted as follows:—

(i) Lower explosion limit (L.E.L.)—hydro-carbon 1.7% by volume. Air 98.3%.

(ii) Upper explosion limit (U.E.L.)—hydro-carbon 11% by volume. Air 89%.

Between these limits the mixture could burn if a source of ignition is present and is, therefore, a potential explosive environment.

Air containing 21% oxygen by volume and mixed with a hydro-carbon vapour produces the characteristics shown in Figure 37. Should gases containing a lower oxygen content be mixed with hydro-carbon, the characteristics change. On board ship the gas (flue gas) is predominently nitrogen.

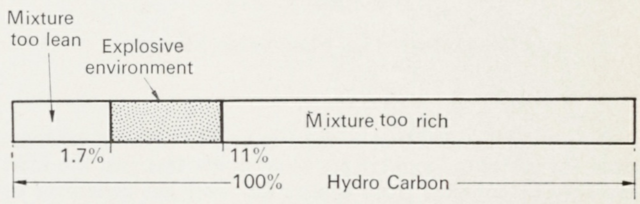


FIG. 37

Inert Gas Characteristics

A typical flue gas from oil burning would comprise, approximately:

Oxygen	2–4% by volume
Carbon-dioxide	12–14% by volume
Sulphur dioxide/trioxide	0.20% by volume
Nitrogen	80.00% by volume
Solids	300 mg/m^3
Water vapour	5.00% by volume.

With this typical mixture of gas, as the oxygen content falls a rapid fall occurs in the upper explosive limit (U.E.L.) and a corresponding but lesser increase in the lower explosive limit (L.E.L.) until at about 11% the two levels meet.

The enclosed area on the graph in Figure 38 is now the flammable area, and any hydro-carbon mixture having an oxygen content of more than 11% by volume is a potential flammable mixture. Below 11% by volume the mixtures are not potentially flammable but, if sufficient air is admitted to the tank, the resultant mixture could change sufficiently to become a potential hazard.

Therefore, it is obvious that it is advantageous to maintain the oxygen content as near as possible to zero, in order to offset any possible effects of any accidental ingress of any air, containing 21% oxygen, to the system.

It is generally accepted that provided the oxygen content is maintained below 5% by volume this would give a realistic safety margin to cover most eventualities. It is also generally agreed that 8% is approaching the danger zone, remembering that 11% by volume cannot be considered a precise figure and that the upper and lower explosive limits may vary with the type of oil cargo carried. Chapter 15, 7.2.3 requires that the capacity of the inert gas system is to be at least sufficient for 125% of maximum discharge capacity of the cargo pumps.

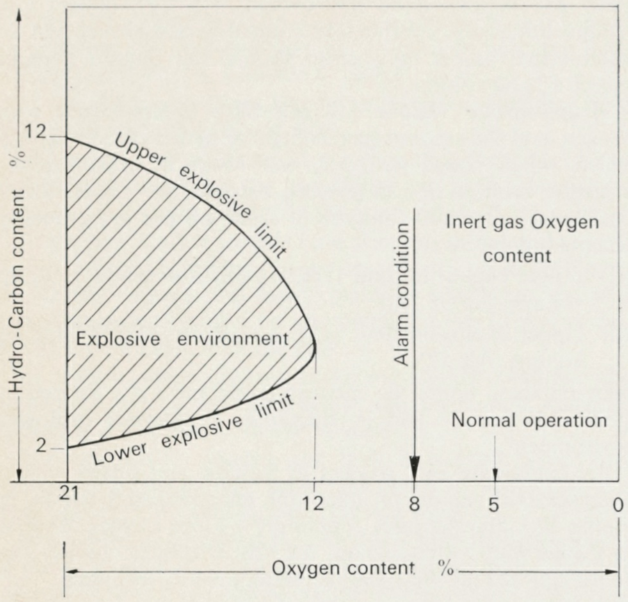


FIG. 38

Graph Inert Gas Flammable Mixture

It should be added that whilst Figure 33 shows an arrangement for deriving the inert gas from boiler flue gas, the inert gas may be supplied from a separate inert gas generator or from a gas turbine unit exhaust. However, with the latter arrangement it would be necessary for the turbine exhaust gas to be led to an after-burner provided with automatic combustion control to reduce the oxygen content, as normal gas turbine exhaust may contain an oxygen content as high as 16% by volume.

The inert gas distribution main on deck is to be provided with a liquid filled pressure/vacuum breaking device to prevent the tanks being subject to a positive pressure of more than 0.024 N/mm^2 (0.24 kg/cm^2) above atmospheric pressure and a negative pressure of more than 0.007 N/mm^2 (0.07 kg/cm^2) below atmospheric pressure. Chapter 15, 7.6.5 requires means to be provided for isolating each tank from the inert gas main. Figure 39 shows a typical inert gas deck system. The scope of the Survey of the various items of inert gas systems is indicated in Appendix II.

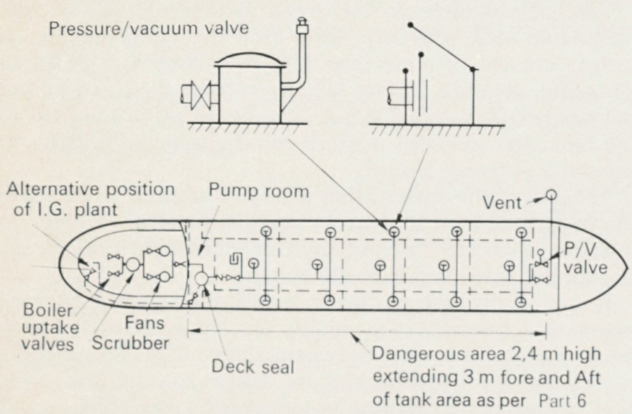


FIG. 39

Inert Gas Deck System

7 FUEL GAS AND CRUDE OIL BURNING ARRANGEMENTS

7.1 Methane (Fuel Gas) Burning

After the advent of the liquefied natural gas carriers the next logical step was to consider some way of making use of the 'boil off' gas in ships' boilers.

The 'boil off' corresponds roughly to 40 tonnes per day per 10 000 tonnes of cargo.

It will, however, be appreciated that in order to utilize this gas as fuel for ships' boilers it will be necessary for the gas to be heated and pressurized.

Gas heaters and compressors of watertight construction are to be located on the open deck, suitably protected against mechanical and environmental damage. Alternatively, they may be located in a well ventilated compartment above main deck level external to the machinery spaces. This compartment, however, would be considered a dangerous space, and accordingly, would be required to have mechanical ventilation of an extraction type capable of not less than 30 air changes per hour, the capacity of air change to be based on the total volume of the compartment.

Figure 40 shows a typical methane burning arrangement from which it will be seen that the 'boil off' gas is drawn from the gas header and is compressed. From the compressors it is discharged to the gas heaters from whence it is led to the fuel gas main.

The fuel gas main in way of the machinery space, is to be located within a mechanically ventilated pipe or duct—the ventilation being of the extraction type, in order to maintain the pressure within the enclosure at less than the surrounding atmosphere. The gas piping must be of seamless or equivalent construction having, as far as practicable, all welded joints. A master shut-off valve is to be located outside the machinery space, and the valve should be arranged to close on failure of the pipe/duct ventilation, gas detection within the enclosure, or the loss of gas pressure within the supply pipe. In addition, this valve should be capable of being operated from within the machinery space.

An alternative to the extraction ventilation arrangements described above would be to pressurize the pipe duct with inert gas to a pressure in excess of the fuel gas pressure.

A ventilation hood or casing is to be provided in way of the boiler front area where valves and flanges for the gas fuel system cannot, for practical reasons, be contained in the double wall piping or ducting.

Continuous gas detection is to be provided in way of the hood and gas pipe ducting and so arranged as to provide visual and audible alarm at 30% lower explosive level (L.E.L.) and shut down of the fuel gas supply before 60% L.E.L. is reached.

Each gas consuming unit is to be provided with a 'block and bleed' arrangement consisting of three automatic valves. Two of these isolating valves are to be located in series in the fuel gas line, the third, being the vent valve, is to be located between the two isolating valves.

Failure of the gas supply, loss of flame, forced draught fan failure, or remote control power source failure will cause the two isolating valves to close and the vent valve to open automatically. Audio-visual alarms are to be provided to indicate low pressure in the oil fuel system in addition to the above conditions.

Provision is to be made for inerting and gas freeing the gas piping within the machinery space. In this respect, the bleed vent valve could be utilized as the inert gas purging inlet, provided alternative arrangements are made for venting to atmosphere. This arrangement is incorporated in Figure 40.

In all cases, the boilers are to be started up using fuel oil only, and each boiler is to be provided with an independent uptake or funnel.

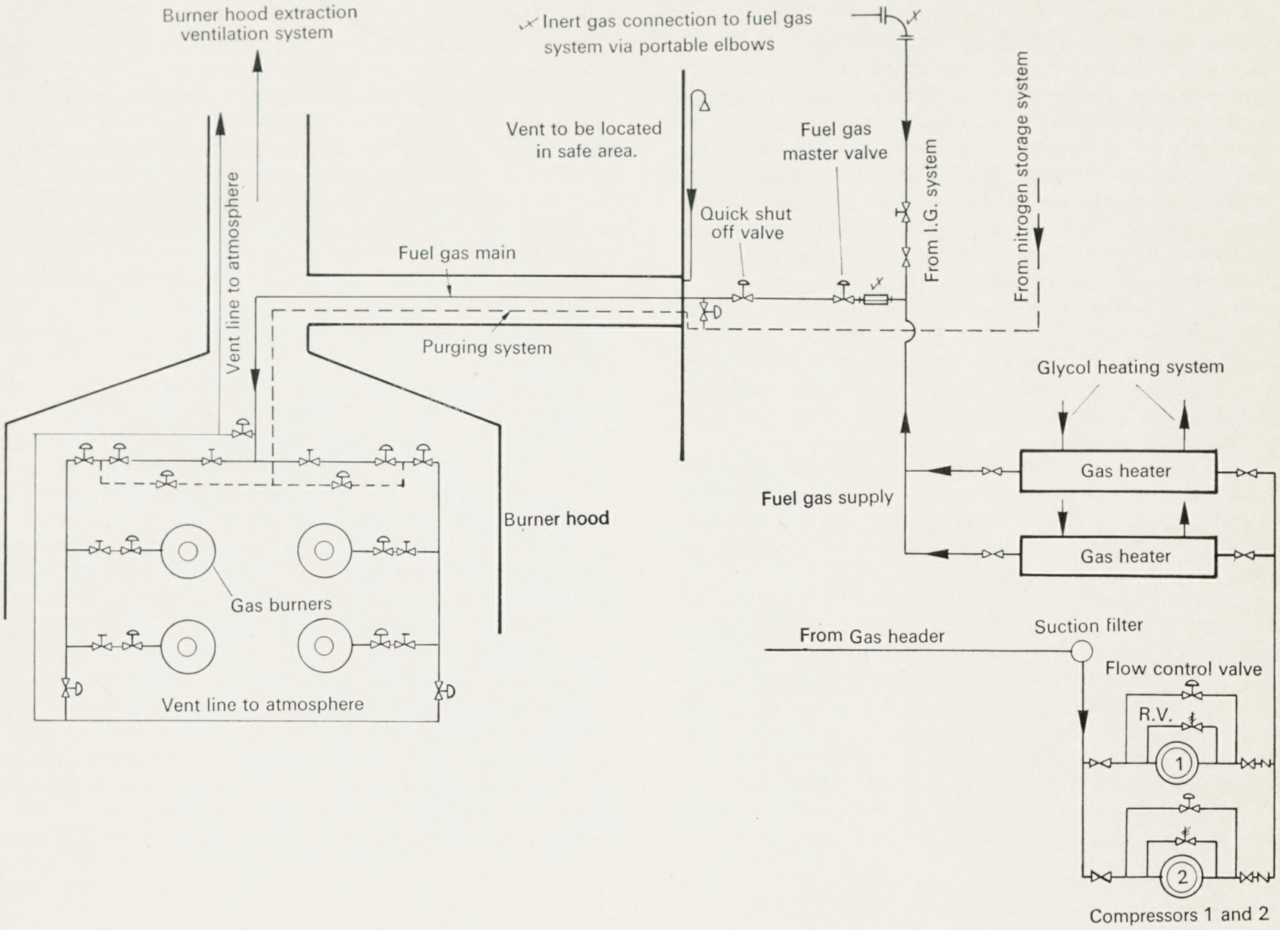


FIG. 40

Typical 'Fuel Gas' Burning Arrangement

The firing unit is to consist of dual fuel (gas and oil) burning equipment, and the arrangements are to be such that fuel gas cannot be admitted to the burners until the oil fuel and combustion air are present, thus obtaining ignition from the fuel oil flame, which must be present at all times. A shut-off cock and a flame arrester are to be provided at each burner unit. The flame arrester may, however, be incorporated in the burner unit. Further locally manually operated shut-off valves are to be provided in the fuel gas supply to each boiler manifold.

One of the problems on an L.N.G. ship is the disposal of 'boil off' whilst in port. Some national authorities object to the venting of the 'boil off' to atmosphere and, therefore, alternative means of disposal have to be provided. This provision, if the port loading arrangements are suitable, can be met by connecting the vent line to a shore return line. Another alternative is to provide an auxiliary boiler suitably arranged for burning fuel gas.

The steam raised in this boiler should be led to a 'dump' condenser and in this way the 'boil off' gas can be dealt with. It may be well to add that the purpose of this boiler is for the disposal of the 'boil off' where no other means are available, and as such there are no steam connections from this boiler to the ship's system.

Alternatively, the 'boil off' could be dealt with by provision of a gas incinerator which would require to be located in a non-hazardous area. Burning arrangements would be required to comply with the requirements previously indicated. Cooling arrangements would be essential in order to ensure the products of combustion leaving the incinerator are cooled well below the temperature corresponding to the ignition point of methane.

It may be pertinent to add that the above refers to the use of methane (L.N.G.) gas only. Proposals to utilize the 'boil off' from liquefied petroleum gas (L.P.G.) have not been accepted.

7.2 **Crude Oil Burning**

The Society has occasionally been requested to approve arrangements for crude oil burning. Whilst these requests have been the exception rather than the rule, it is believed that more interest may now be taken in the possibility of using crude oil in connection with main steam generating purposes. This interest, perhaps, being particularly from offshore services utilizing ship type crude oil storage units in conjuction with production facilities.

In the circumstances it may be pertinent to indicate the requirements to be complied with when considering such arrangements.

It will be appreciated that crude oil is a low flash point fuel and would not normally be accepted for use in fuel burning systems in the machinery spaces in ships. However, consideration is given on the basis of the Rules for methane burning as indicated in the Rules for Carriage of Liquefied Gases in Bulk, Chapter 16.

The International Association of Classification Societies (I.A.C.S.) Regulation No. 100, gives some guidance in the form of 'Rules Concerning Use of Crude Oil or Slops as Fuel for Tanker Boilers'.

As with methane burning arrangements, all piping conveying low flash point fuel, i.e. crude oil, must be of seamless or equivalent construction with all welded joints, and led through a double wall pipe or duct. Also, the burner units and associated valves are to be located in a gas tight duct or double casing in way of the boiler front. A ventilation hood should be provided in way of valves, flanges, etc., which cannot for practical reasons be accommodated within the duct or casing.

The crude oil enclosure and hood are to be provided with mechanical ventilation of the extraction type and monitored for gas leakage. Audio-visual alarms are to be provided in the machinery room and pump room.

Crude oil differs from methane in many important aspects and, in particular, its vapour may be heavier than air. Consequently, any vapour leakage may tend to settle in the lower parts of the spaces involved. Therefore, efficient mechanical ventilation of extraction type is necessary to ensure adequate ventilation of the spaces.

A percentage of open mesh floor plates is required in the machinery spaces, and extraction ducts should be located in way of the bilges, port and starboard, to ensure adequate ventilation with the duct discharges led to a safe position on the open deck.

The crude oil pumps, heaters, filters and ancillary units are to be located in well ventilated compartments external to the machinery spaces, but, in all weather conditions they should be accessible from the weather deck. Essential valves are to be capable of being operated from the machinery spaces in addition to their local operation within the pump room.

Ventilation of the pump room must be in accordance with normal tanker ventilation practice, and the pump room fans are to be interlocked with the crude oil unit pressure pumps so that the fans must be running in order to operate the pumps. The exhaust fan motors are to be located external to the ventilation ducting.

The crude oil pumps are to be capable of being controlled from the machinery space in addition to the pump room. Isolating shut-off valves fitted in the crude oil supply pipe in the pump room and at the boiler front, are to be capable of local manual control in addition to any remote/automatic controls. An audio-visual alarm is to be provided to indicate low fuel pressure, also means are to be provided to ensure automatic shut-off of the burner fuel supply in the event of flame failure.

Provision is to be made for purging the combustion chamber prior to lighting the burners, also for purging the crude oil fuel supply pipes before opening up for inspection/repair purposes.

Arrangements are to be made to enable the crude oil lines to be drained to a suitable drain tank in the pump room. A drain pipe from the lowest part of the pipe ducting to the drain tank should be provided and fitted with a self-closing valve.

Separate fuel oil tanks are to be provided for heavy fuel oil, and the supply lines from the heavy fuel oil and crude oil systems are to be led to an 'L' ported cock so that the systems may be readily connected to one fuel or the other. Alternatively, the heavy fuel and crude oil supply lines may be led to an 'L' ported switch cock located within the double casing at the boiler front. The 'L' ported cocks are to be capable of manual control external to the pipe ducting mentioned above.

All remote control valves are to be capable of local manual operation, while control valves within the double casing are to be fitted with extended spindles with gas tight glands. Relief valves provided in the crude oil fuel lines are to discharge in closed circuit to the suction side of the pumps.

Figure No. 41 shows a possible crude oil burning system.

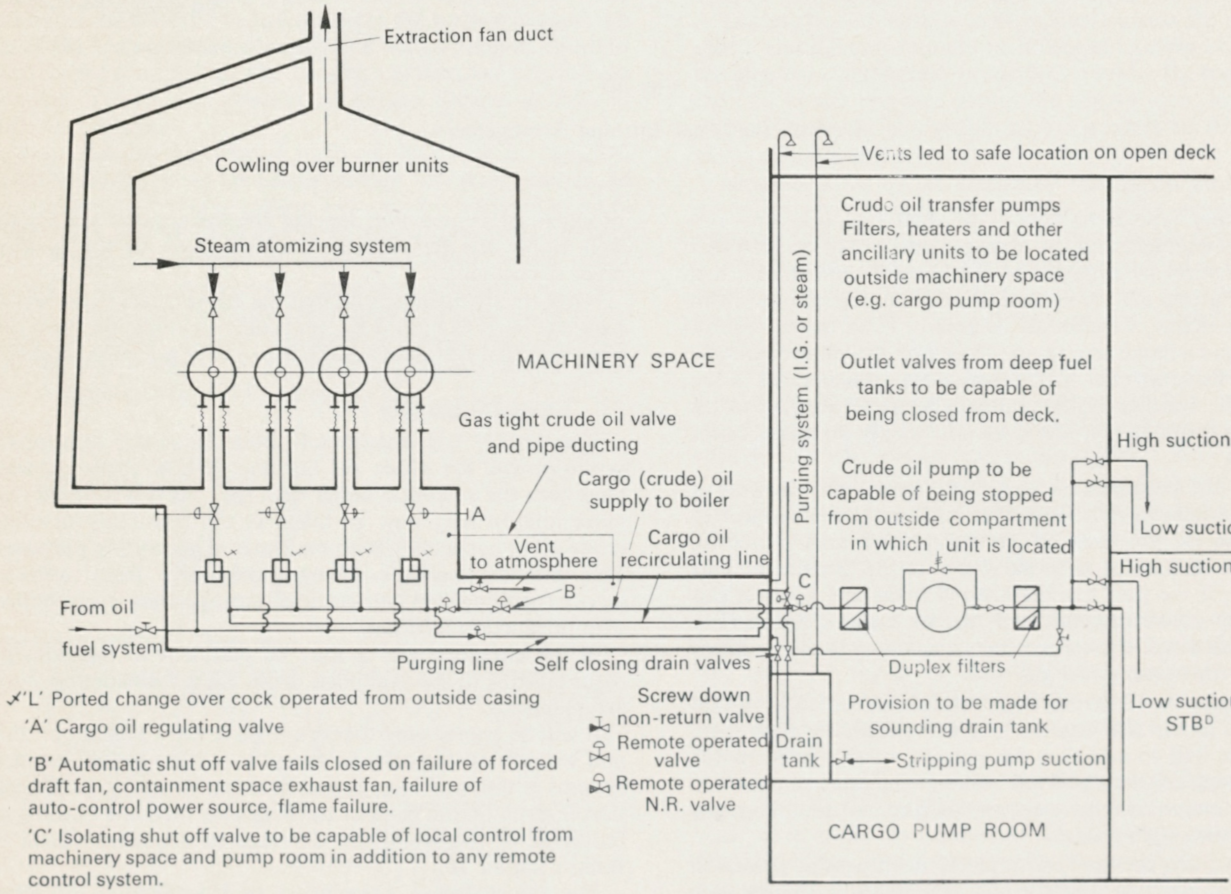


FIG. 41

Typical 'Crude Oil' Burning Arrangements

8 REQUIREMENTS FOR OTHER SPECIALIZED SHIPS

8.1 Ore Carriers

In ships of this type it is essential that the holds should be clear of pipes and fittings which could be damaged by grabs. Therefore, it is usual to lead the hold bilge suction pipes through the double bottom or wing deep ballast tanks to the bilge valves in the machinery space or pump room.

The pipes should be of heavier gauge than that normally used, and if they pass through deep tanks, non-return valves of approved type should be fitted on the open ends of the bilge suctions in the holds.

It is sometimes proposed that a ring bilge main be fitted in the wing ballast tanks and that the hold bilge suctions should be connected to the main. Such an arrangement is not acceptable as bilge valves are required to be in positions where they are at all times readily accessible. Sounding pipes for the hold bilge wells should preferably be fitted in the holds and be protected by heavily sectioned guard plates. If this is not practicable, the sounding pipes should be led through the wing ballast tanks and connected to the bilge wells by elbow pipes. The sounding and elbow pipes should be of extra heavy thickness and galvanized inside and out. Figure 42 shows a suitable arrangement of elbow sounding pipes.

In most of these ships, the water ballast suctions are led to a ring ballast main running through the wing ballast tanks, all valves being operated by means of extended spindles led to deck. An alternative arrangement is to lead the ballast main through fore-and-after pipe tunnels within the double bottom, and to fit all tank valves for wing and double bottom tanks in the tunnels. Access for the operation of the valves is provided from the machinery space. Incidentally, there would be no objection to a bilge line being fitted in the tunnels having branches to the hold bilges.

A problem may arise in connection with the air and overflow pipes from the wing ballast tanks. These tanks have to be filled and emptied rapidly and for this purpose they have large diameter suction and filling connections. It is considered very desirable that air pipes of Rule area should be fitted, especially in the case where ball type float valves are fitted in the air pipes. This is in order to prevent damage to the tanks due to the ball valves being lifted into the closed position due to vacuum formed during deballasting.

8.2 Ore/Bulk/Oil Carriers

In general, with this type of ship, the arrangements are such that the centre holds/tanks only are used for the carriage of bulk or ore cargoes, while the wing tanks and centre holds/tanks can be used for the carriage of oil cargoes.

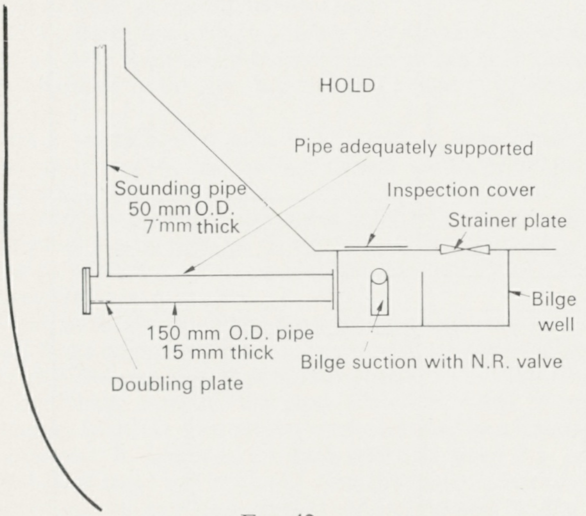


FIG. 42

Ore Carrier Elbow Sounding Arrangements for Hold

With regard to the pumping arrangements, it will be appreciated that the ship has also to be considered as an oil tanker, and the piping arrangements for the cargo system must have no connection with the pumping arrangements in the machinery space.

Accordingly, the pipes are led to a pump room as in normal tanker practice. In this respect it should be added that from the pumping and piping point of view slop tanks are considered as cargo oil tanks.

The stripping connections from the cargo hold/oil spaces are also considered as the bilge suctions from these spaces when used for the carriage of dry cargo. The suctions should be separate from the stripping line of the wing tanks and have S.D.N.R. valves fitted in readily accessible positions. The valves are to be capable of local manual control. The bilge/stripping line should be led to two stripping pumps of the self-priming type, the capacity of which is to be in accordance with the Rules.

There should be no connection between the bilge/stripping line and the cargo oil main, wing stripping line or sea water lines. All main cargo valves, including suctions from the wing tanks, if fitted, are to be blanked off when dry cargo is carried.

If water ballast tanks are fitted under the ore/oil holds, the suctions from these tanks should be led to a suitable pump in the pump room. In general, oil fuel should not be carried in these double bottom tanks.

Access arrangements to the double bottom tanks should be via trunkways led to deck at the forward end of each of these spaces.

Air and sounding pipes from the double bottom tanks should be via these trunkways and not through the cargo tanks. If this is impracticable, the air and sounding pipes should be in one continuous length or connected by welded joints. The thickness of the pipes is to be not less than 12.5 mm and the sounding rod used should be of brass or similar non-sparking material.

If pipe tunnels are provided it will be necessary for provision to be made for gas freeing these spaces, and access should be provided at each end of the tunnels. The access at the aft end of the tunnel may be via the pump room, and mechanical ventilation of the pipe tunnels should be provided. A notice board should be fitted at each entrance to the tunnel stating that, before any attempt is made to enter the tunnels, the ventilating fan must have been in operation for an adequate period. In addition, the atmosphere in the tunnels should be sampled by a reliable gas indicator. All bilge and ballast valves located in the pipe tunnels are to be capable of local manual control in addition to any remote control.

Other arrangements have been accepted whereby the cargo holds extend the full width of the ship, and double bottom and topside tanks are provided for water ballast only. These tanks may be common, having an interconnecting ballast duct between the double bottom and topside tank or a separate independent ballast connection.

Figure 43 shows a general arrangement of such a ship, while the transverse section shows alternative ballasting arrangements.

In all cases, irrespective of the type of pumping and piping arrangements provided, it will be necessary for the ship to be gas freed before dry cargo is loaded.

8.2.1 Slop Tanks in Combined Ore/Oil Carriers

With the ore, bulk and oil carrier (O.B.O. ship) now so numerous, an obvious difficulty is that of ensuring that the vessel is totally gas free before loading dry cargo.

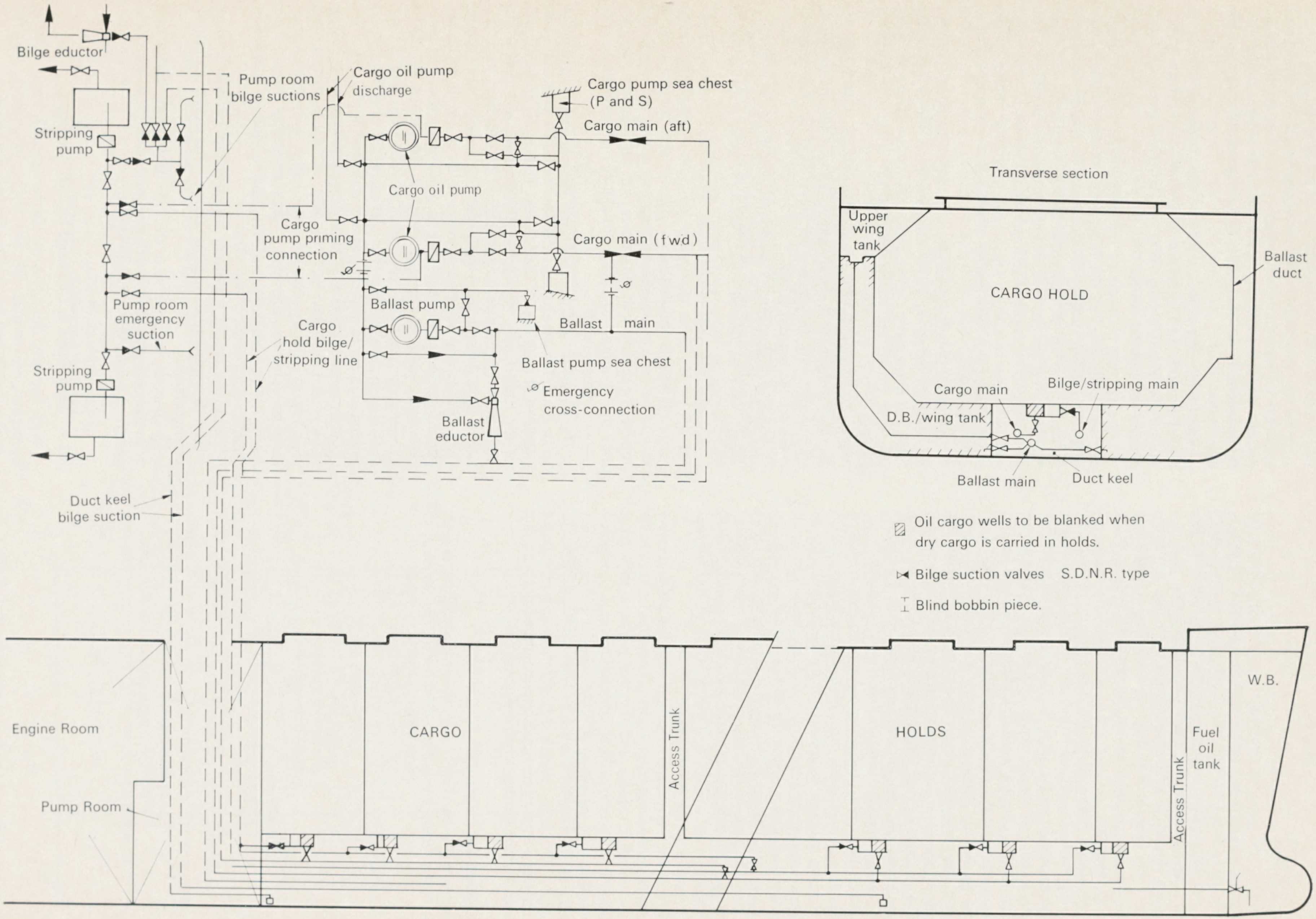


FIG. 43

Cargo Oil Hold Drainage System (O.B.O.)

Normal operation would require that all spaces, including slop tanks, should be gas freed. However, consideration has now been given to the carriage of cargo oil slops in slop tanks when the vessel is carrying dry cargo. If it is anticipated or intended that the slop tanks of combined ore/oil carriers contain oil slops, when the ship is loading or carrying dry cargo, then the following requirements are to be complied with:—

(i) The slop tanks are to be separated from the cargo holds, machinery space and all other safe spaces by means of a cofferdam or equivalent.

(ii) A completely separate pumping system is to be provided for the slop tanks, or alternatively, all suction and filling connections for the slop tanks are to be provided with spectacle blank flanges.

(iii) Separate vapour pipes are to be provided for the slop tanks.

(iv) Adequate ventilation is to be provided for the spaces surrounding the slop tanks, and at least two gas detectors are to be provided for testing these spaces.

(v) Provision is to be made for locking shut all hatches and other openings to the slop tanks, and the keys are to be kept in the custody of the Master.

(vi) Notice boards are to be placed at suitable points, detailing the precautions to be observed prior to the vessel loading and whilst carrying dry cargo with liquid in the slop tanks.

In order to satisfy the requirements of certain national and/or cargo terminal authorities, it may be necessary to provide an inert gas system for blanketing the slop tank contents.

8.3 Container Ships

This type of ship is essentially a dry cargo ship, the construction of which has been specially adapted for the carriage of cargo in containers. The pumping arrangements are generally similar to those of a normal cargo ship.

Occasionally, plans are received showing the bilge and ballast valves located in the hold spaces instead of in the machinery space or in pipe tunnels, as is the normal practice. With this arrangement, however, the valves in the hold would be accessible, as required by the Rules when containers are carried, but this may not necessarily be the case when the vessel is used for the carriage of other cargoes. Therefore, the bilge and ballast valves should be either enclosed in pipe tunnels or fitted in the machinery space.

It is, however, the writer's opinion that the above arrangement could be accepted, provided a class notation is affixed to the character of the ship, e.g. 'Holds Limited to Container Cargo'.

With a vessel having such a notation, no consideration would be given to the carriage of any cargo other than containers.

According to the Rules, the valves in the holds are required to be readily accessible at all times, and in this respect it would be necessary for access hatches and ladders or companionways to be provided.

Where hold bilge sounding pipes pass through deep water-ballast tanks, and/or sounding pipes from deep water-ballast tanks pass through hold spaces, they should be not less than 12.5 mm thick. Further, the pipes should be fitted in one continuous length or with welded joints and must be adequately supported. If, however, an undertaking is given that the water-ballast tanks will be empty when dry cargo is carried, it is considered the sounding pipes could be accepted having a reduced thickness, but in no case should the thickness be less than 7 mm.

This may seem contrary to the requirements of Chapter 12, Table 12.2.4, but it will be noted that this table refers to minimum thickness of pipes. Further, in the case of bilge pipes passing through deep tanks, Chapter 13.7.11 requires that such pipes should be fitted with non-return valves at the open ends to prevent flooding of the hold in the event of failure of the pipe. This requirement obviously cannot be applied in the case of sounding pipes, and it is the Author's view that extra precautions should be taken by increasing the pipe thickness as indicated.

In Regulation 27 of the 1966 'Load Line Convention', reference is made to the prevention of progressive flooding due to damage. This requirement is particularly applicable to 'B' type ships which are eligible for deeper loading, i.e. to B-30, or B-60 freeboard, when the requirements of Chapter 13.1.2, 2a and 2b will have to be complied with.

8.4 Coasters

Figure 44 shows a ship pumping plan and a diagram of pumping arrangements in the machinery space for a typical coaster. It will be observed that the tank suctions and air pipes are of uniform size. This practice is strongly recommended for small ships with a view to avoiding confusion and mistakes related to the area of the air pipes.

Normally there is only one cargo hold, and if this is over 35.5 m long, additional bilge suctions are to be provided in the forward part of the hold, as required by Chapter 13, 3.2.1. Some builders fit a levelling pipe of extra heavy thickness in the double bottom between the port and starboard bilges at the extreme forward end of the hold. With this arrangement only one bilge suction is necessary and may be fitted in either bilge.

Usually the forepeak suction pipe is led through the hold, but it is the practice among some Continental builders to connect this suction to the wash deck line, and to join this line to the ballast main in the engine room. The wash deck line can then be used for pumping out and filling the forepeak. Such an arrangement has been accepted by the Society for many years.

The main disadvantage with such an arrangement is that the suction lift will be in the region of 4.5 m when the tank is nearly empty, and bearing in mind the length of pipe and the number of bends in it, there may be some difficulty in pumping out the tank. The deck water ballast tanks have filling connections from the wash deck line and are emptied by merely opening a valve secured to the tank plating, allowing the water to run on to the deck and over the ship's side by way of the scuppers.

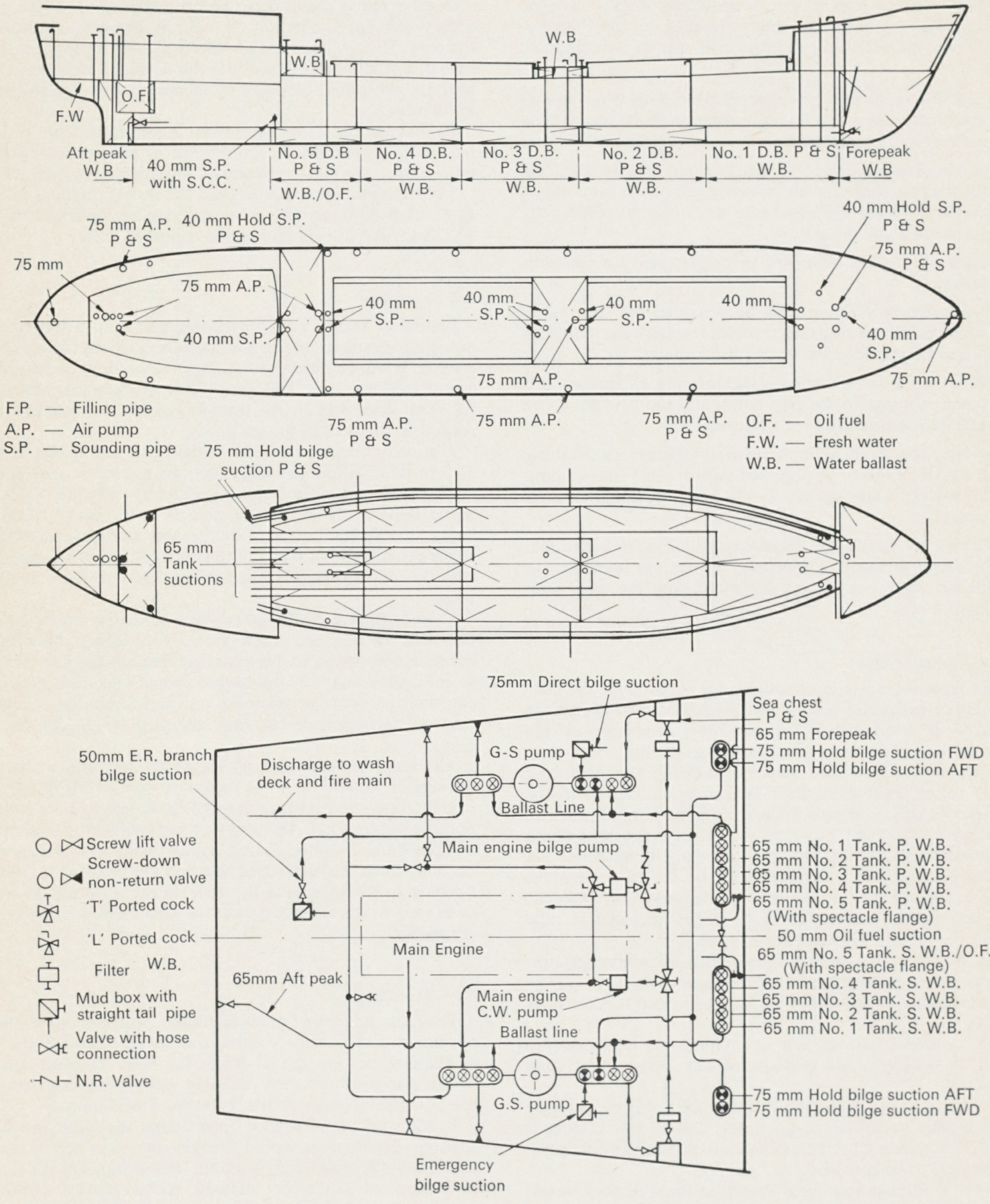
8.5 Trawlers

Trawlers are now predominantly provided with diesel powered main machinery units, and having regard to the size of these ships, the special Rules for Steel Trawlers are no longer published, and the pumping and piping arrangements are now incorporated in the Rules for Steel Ships.

In the case of ships with open floors, the minimum bilge suction requirements would include one branch, one direct and one emergency bilge suction. The arrangements shown in Figure 44 could be adapted for a trawler, modified as necessary to suit the different arrangements of tanks and compartments.

8.6 Tugs

It is frequently observed that on pumping plans of tugs no provision is made for the draining of the accommodation space forward of the engine room. In most cases this space is situated above the tanks used for the carriage of oil fuel or



1 Dimensions of ship = 51,5 m × 9,2 m × 4 m

2 Size of bilge main = $\sqrt{2{,}78 \times 51{,}5 \times 13{,}2 + 26}$ = 70 mm Proposed size = 75 mm

3 Rule capacity of bilge pump = 28 m^3/Hr Proposed size = 35 mm^3/Hr

FIG. 44

Coaster: Ship's Pumping Diagram

fresh water, and drainage may be arranged in one of the following ways:—

(i) A bilge suction led to the main bilge line.

(ii) Hand pump suction.

(iii) Drain valve on the engine room side of the bulkhead, with control to deck and an open/closed indicator at deck level.

(iv) Trapped scupper, with a non-return flap valve, to a cofferdam provided with a bilge suction.

When the accommodation is not situated above tanks, hand or power pump bilge suctions are the only practicable means of drainage.

If there is an accommodation or store flat at the after end of the machinery space, this may be drained by means of a scupper led to the engine room and fitted with a self-closing cock, as permitted for trawlers.

Before a tug, or any other self-propelled ship for that matter can proceed to sea even for coastal voyages, it is necessary for two bilge pumps of Rule capacity to be provided. When there is a class notation restricting the ship to harbour or river service, concessions may be made consisting of a reduction in pumping capacity and/or the acceptance of a hand pump in place of one of the power pumps. It is not possible to lay down a definite ruling on this matter as so much depends upon the actual service, and the size and power of the ship. Generally, the question of concession only arises in the case of the smallest tugs, as most vessels of this type have an independently driven general service pump of reasonable capacity. This is normally supplemented by the main engine driven bilge pump, which usually ensures that Rule requirements are complied with.

There are advantages in keeping bilge and ballast pumping arrangements on a tug as simple as possible, and Figure 45 shows a diagram which could form a basis for such an arrangement on the smaller vessels of this type. Large tugs may have pumping arrangements in the engine room based on those as illustrated for a coaster.

8.7 Yachts

In the current Rules for Wood and Composite Yachts the formula for the size of the main bilge line is $D = \frac{L}{1.2} + 25$

where D = internal diameter (mm).

L = Rule length of yacht (m).

No pipe, however, is to have an internal diameter less than 25 mm. It would appear from paragraph 8506 of the above Rules that yachts up to 22.5 m need only be provided with a single hand pump for bilge pumping duties. The Author does not necessarily agree with this, and would suggest that this requirement should be restricted to yachts up to and including 15 m.

Further, yachts over 15 m and up to 30 m should be required to have not less than two pumps for bilge service, one of which may be a hand pump. For yachts over 30 m the arrangements should be in accordance with the table shown in the Rules. Figure 46 shows a simple scheme for a power pump combined with a hand pump.

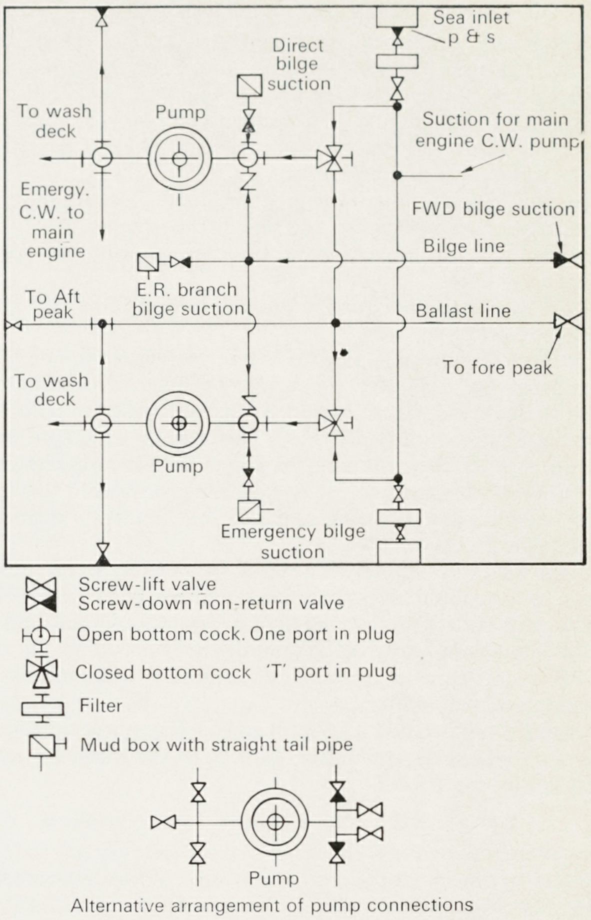


FIG. 45

Tug: Pumping Diagram

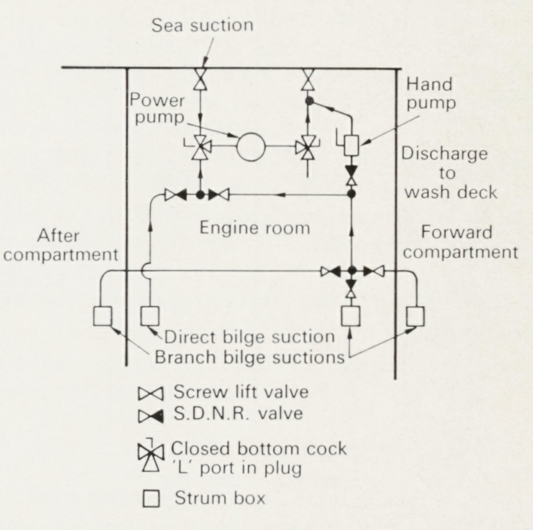


FIG. 46

Yacht Bilge Pumping System

9 DYNAMICALLY SUPPORTED CRAFT

9.1 Definitions

A dynamically supported craft is a craft which is operable on or above water and is intended to carry passengers and/or cargo. The above includes air cushioned vehicles. Hovercraft and hydrofoil ships are defined as follows.

'Air cushion vehicle' (hovercraft) is a craft such that the whole or a significant part of its weight can be supported, whether at rest or in motion, by a continuously generated cushion of air, dependent for its effectiveness on the proximity of the surface over which the craft operates.

'Hydrofoil' is a craft which is supported above the water surface in normal operating conditions by hydrodynamic forces generated on foils.

9.2 **Air Cushion Vehicle (A.C.V.) (Hovercraft)**

The Society published Guidance Notes for the Classification of Air Cushion Vehicles in 1970, and Class Notations are indicated in Section 3 of the above Guidance Notes.

Pumping and piping arrangements for these units are normally dealt with on the same basis as that of passenger ships having a restricted service.

In this respect, provision is to be made for draining all watertight compartments, and the arrangements are to be designed so as to prevent water flooding from one compartment to another.

Not less than two pumps should be available for bilge pumping purposes.

It is sometimes proposed to locate individual submersible pumps in the separate compartments, and no objection is seen to this arrangement provided a second means of pumping out these spaces is also provided. This may be an independent pump, located above the main deck level, with suction branches led to each compartment. It is, however, considered this unit should be capable of being operated independently from the main power source.

Bilge suctions should, in general, be not less than 50 mm bore, but reduced sizes may be accepted, each case being dealt with on its merits, but in no case should the branch bilge suctions be less than 25 mm diameter.

All compartments should be provided with means of venting and sounding.

Standby oil fuel, lubricating oil and cooling water pumps are to be provided as applicable, subject to the Class notation and service intended.

9.3 **Hydrofoils**

The hydrofoil is a seaborne craft and as such, from the point of view of Classification, has to comply with the Rules for Steel Ships, with due consideration being given to class and service limits. To date, all hydrofoil craft classed with this Society have been considered as passenger ships, but have been approved on the basis of restricted service.

In this latter respect, some concession is given to the requirements for bilge pumps, and the usual requirement is for two independent power pumps to be provided. Having regard to the restricted size of the main machinery rooms, it is usual in the case of twin screw units for the bilge pumps to be main engine driven, and as these engines can be declutched from the propeller shaft, this arrangement has been accepted.

In addition, a third (emergency) bilge pump is to be provided outside the machinery space, and this pump may be a hand pump other than the lever type, or an independently driven power pump. As in the case of passenger ships the bilge main is to be situated inboard of the B/5 line, and all bilge suctions are to be capable of being controlled from deck. Subject to the hydrofoil being restricted to harbour, or sheltered waters within 110 kilometres from the port of departure and not more than 24 kilometres from the coast, standby lubricating oil or cooling water pumps have not been insisted upon.

Figure 47 shows a typical acceptable pumping arrangement for this type of craft.

Having regard to the material of construction and the restricted service of these craft, outlet valves have not been

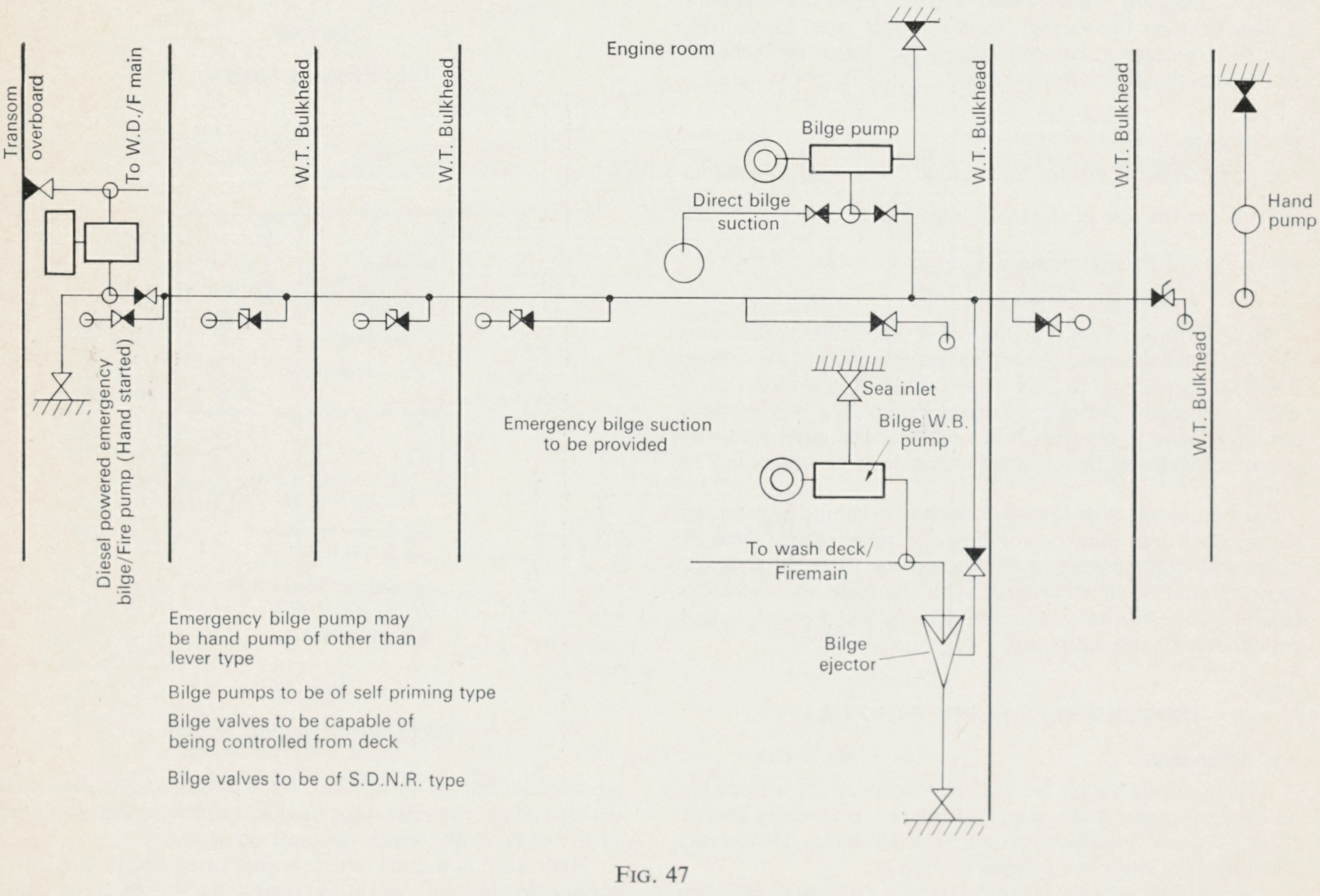


FIG. 47

Hydrofoil Pumping System

insisted upon for the exhaust pipes subject to:

(i) The main exhaust pipe being of extra heavy gauge but not less than the hull thickness in way.

(ii) The main engine auxiliary exhaust being not less than, say, 30 cm at its lower edge above the water line.

The auxiliary exhaust being utilized only when the craft is hull borne, prior to planing on the hydrofoils when the exhaust passes through the bottom of the vessel.

The exhaust pipes are usually of stainless steel and Figure 48 shows a typical exhaust arrangement.

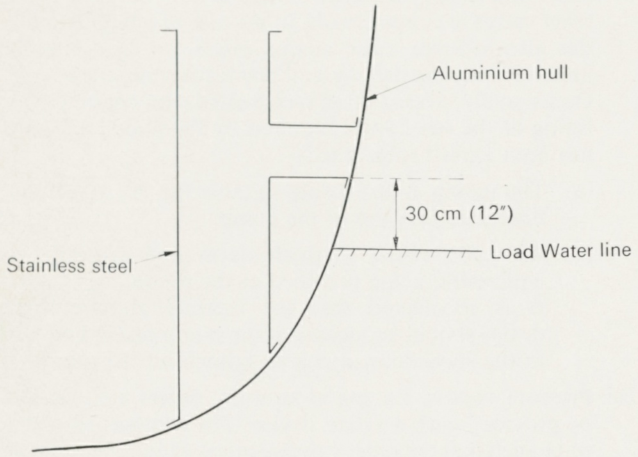


FIG. 48

Hydrofoil Exhaust and (Shipside) Arrangements

10 MISCELLANEOUS ITEMS

10.1 Shipside Valves

Chapter 13, 2.6.7 requires shipside valves to be of steel or other approved ductile material. Ordinary cast iron is not acceptable, but spheroidal graphite iron to BS 2789 grade 420/12, or equivalent, is acceptable for the purpose. The valves are to be made at approved foundries, in accordance with Part 2, Chapters 4 and 7 of the Rules.

10.2 Flexible Hose

In the main, all piping systems for essential services are to be of approved metallic construction. However, flexible hose of approved type has been accepted as short joining lengths between permanent piping systems and items of machinery where flexibility is essential, Chapter 12, 6.1.1. The requirements for flexible hose are also given in Appendix III.

10.3 Plastics Pipes

There is a considerable amount of interest expressed by shipowners and shipbuilders in the possible use of plastics piping, and the Society is prepared to consider the proposals to fit such pipes where they can be used with advantage and safety. One serious disadvantage of plastics pipes, which makes them unsuitable for many essential services on ships, is that they are either flammable or quickly damaged by flames or heat.

Further, the strength of plastics piping is generally much less than that of metallic piping.

Such pipes have, to date, only been accepted for use in non-essential services, as outlined in Chapter 12, 5.2.1.

10.4 Bottled Petroleum Gas as Fuel in Galleys

Some of the smaller vessels have cooking ranges using butane gas, 'Calor gas', as fuel. The Society however, has no published requirements relating to such installations, and the fitting of which is primarily a matter for agreement between owners and builders.

In British ships, the galleys must comply with the Merchant Shipping (Crew Accommodation) Regulations. And the Department of Trade and Industry in their handbook on Crew Accommodation state that:—

> 'Ranges using gas for fuel require special precautions. The galley space should be well ventilated, and one ventilator should be trunked to the floor. The gas piping should be of solid drawn metal with a minimum number of joints, and with sufficient flexibility to obviate strain. The stove, gas containers and piping should be adequately secured and the supply of gas should be capable of being shut off from the open deck or some other safe position. The gas containers should preferably be sited on deck, but if placed in an enclosed space the space should be adequately ventilated. The gas should have a characteristic smell so that a leakage can be readily detected.'

Additional detailed information in connection with the use of this fuel on ships can be found in the following publications:—

> British Standard Code of Practice CP 339: Part 3 (1956). Domestic Butane Gas-Burning Installations Part 3: Installations in Boats, Yachts and Other Vessels.

10.5 Resilient Seated Valves (Butterfly/Ball Valves)

The Society is often requested by manufacturers for information on the use of resilient seated valves in systems additional to those for which these valves are normally accepted, and in particular for use in 'oil' systems.

It is the Society's normal practice to require valves in oil fuel and lubricating oil systems to be of the normal metal to metal seating type.

However, it has been agreed that resilient seated valves previously accepted for use on double bottom tanks, and then only when located in a closed pipe tunnel or duct keel, could also be accepted for use as 'in-line' valves in low pressure systems in machinery spaces, but not as terminal valves on tanks or piping systems, subject to the following requirements being complied with:—

(i) The design is such that failure of the non-metallic seal would not result in external leakage.

(ii) The location of the valve is such that failure of the valve to seal would not prevent transfer of oil to settling or service tanks.

(iii) The valves to have normal metal to metal flanged joints.

(iv) The valves to be installed to the Surveyor's satisfaction.

For other systems for which resilient seated valves have been accepted, *see* Appendix IV.

11 OFFSHORE SERVICES

11.1 Piping Arrangements

Where the machinery and piping systems of offshore units are essential to the safety of the unit, then they should comply with the Rules for Steel Ships. The specialized drilling or production machinery will only be considered in so far as it affects the safety of the drilling rig/platforms, and in this respect conformity with a national and/or recognized standard may normally be sufficient. It is, however, essential that the systems are installed and tested to the Surveyor's satisfaction, and diagrammatic plans of the drilling and/or production systems should be submitted to Head Office for consideration.

11.2 Fixed Drilling/Production Platforms

These platforms should be considered as marine units and instructions have been issued to this effect, and only those items of machinery essential to the safety of the platforms are required to be constructed under survey, as in the case of mobile offshore units. It is considered that the essential system on a fixed platform is the fire fighting system, including sensors, alarms and cut-outs. Since this equipment is essentially electrically operated it follows that the generators, their prime movers and ancillary equipment, must also be considered essential and, therefore, should be constructed under survey. However, as only a small amount of power is required for the essential service in relation to the total amount of power available, construction under survey is not insisted upon provided the generators and prime movers are constructed to nationally recognized standards and the units are installed and tested to the Surveyor's satisfaction, each case being dealt with on its merits.

When dealing with plans, consideration should be given to the location of various items of machinery in relation to hazardous areas, referred to as 0, 1 and 2 areas.

Division 0 area	An area in which a dangerous atmosphere could continually be present.
Division 1 area	An area in which a dangerous atmosphere is likely to occur under normal operating conditions, e.g. crude oil-mud pump room, drill area, etc.
Division 2 area	An area in which a dangerous atmosphere is likely to occur only under abnormal operating conditions, e.g. due to pipe failure.

11.2.1 Paragraph D 112 of the Rules for Mobile Offshore Units requires boilers or other fired appliances to be located in safe spaces, and special attention must be given to their location with regard to the above classified areas. Access to the machinery spaces must be from deck.

The ventilation arrangements for safe and hazardous compartments are to be entirely separate, and the inlets and exhausts are to be suitably located to reduce the danger of cross contamination.

11.2.2 Paragraph D 109 states that oil engine exhausts must be fitted with efficient spark arresters, but this does not include gas turbine exhausts.

However, it is considered essential that some means of preventing the emission of sparks from any exhaust should be provided. Air inlets and exhausts are to be located in safe spaces.

11.2.3 Access to safe spaces should be from the open deck, and there should be no direct inter-communication between the safe and dangerous spaces (accommodation and mud rooms, etc.).

11.2.4 It is advisable that audio-visual alarms are provided to indicate the presence of low flash point vapours at the air inlets to the diesel and gas turbine units.

Provision should also be made to prevent the oil engines from over-speeding in the event of accidental ingestion of low flash point vapour. Whilst this can be dealt with for diesel units, it is not always practicable in the case of gas turbines, and therefore, it is not insisted upon. It is, however, essential that the air intake for these units is led from a safe space and preferably overhung from the platform. Gas detectors/alarms should be provided on the external length of the air trunking to indicate the presence of gas in order that suitable precautions, such as the shut down of the unit, can be taken. A high level audio-visual alarm should be provided in the mud tank, in order that warning can be given of a potential hazard.

11.3 Gas and Oil Production Systems

Plans are examined and commented upon as considered necessary, particular attention being paid to the following:—

(i) Materials are to be suitable for the service intended. Terminal valves in the gas and/or oil production systems should be of an approved type.

(ii) Lubricating oil and fuel oil systems should be in accordance with the Rules for Steel Ships. In this respect, the Rules require that all oil pumps and cargo oil pumps are to be capable of being stopped from outside the area in which they are located, in addition to any local manual control. Further, all such pumps are to be fitted with relief valves in closed circuit. In the case of offshore units, this also includes those pumps which are used in conjunction with the drilling and production systems. Occasionally, dispensation is requested with regard to the fitting of the relief valve required by the Rules, and this has been agreed subject to:—

  (a) The piping system being suitable for the maximum discharge pressure of the pump.

  (b) An audio-visual thermal alarm and cut-out, or equivalent, being provided at the pump. It is considered that the thermal alarm/cut-out device should be located at the pump casing and not in the suction or discharge branch on the pump.

(iii) Pressure vessels, i.e. gas separators, dryers etc., should be provided with a safety device. The arrangements are to be such that the relief valves/devices cannot be isolated from the pressure vessels or piping systems.

(iv) Safety valves should be provided with easing gear capable of being operated from a readily accessible position for fired units only.

(v) If blocking valves are to be fitted in conjunction with safety valves, not less than two such safety valves should be provided. The blocking valves are to be suitably interlocked in order that both safety valves cannot be isolated simultaneously. Figure 49 shows an acceptable interlocking arrangement.

(vi) Where fuel gas firing arrangements are provided, then these are to comply, in so far as they are applicable, with the requirements for methane burning (*see* Rules for Carriage of Liquefied Natural Gas, Chapter 16).

Offshore units also include single point mooring buoys, flare stacks and storage spars, all of which require individual attention. In the case of submerged piping, consideration must be given to structural strength and collapsing pressure, since such units can operate in depths as much as 152 m.

In the case of single point mooring buoys for loading/discharging oil tankers, attention must be given to outside loading forces in addition to any pressure forces. Attention must also be given to the lubrication arrangements of the turntable and central pipe swivel joints, as adequate lubrication is essential if the units are to operate without recourse to constant overhaul and repair.

11.4 Location of Oil/Gas Fired Units

11.4.1 Diesel and Turbine Units

Diesel and turbine units should be located in safe areas, and venting systems are to be led from, and outlets located in, safe areas.

With prime mover units incorporating dual fuel systems, the 'low flash' point hydro-carbon fuel piping in way of the safe areas should be led through gas tight ducting/cofferdams, and provision is to be made for indicating any leakage within the trunking.

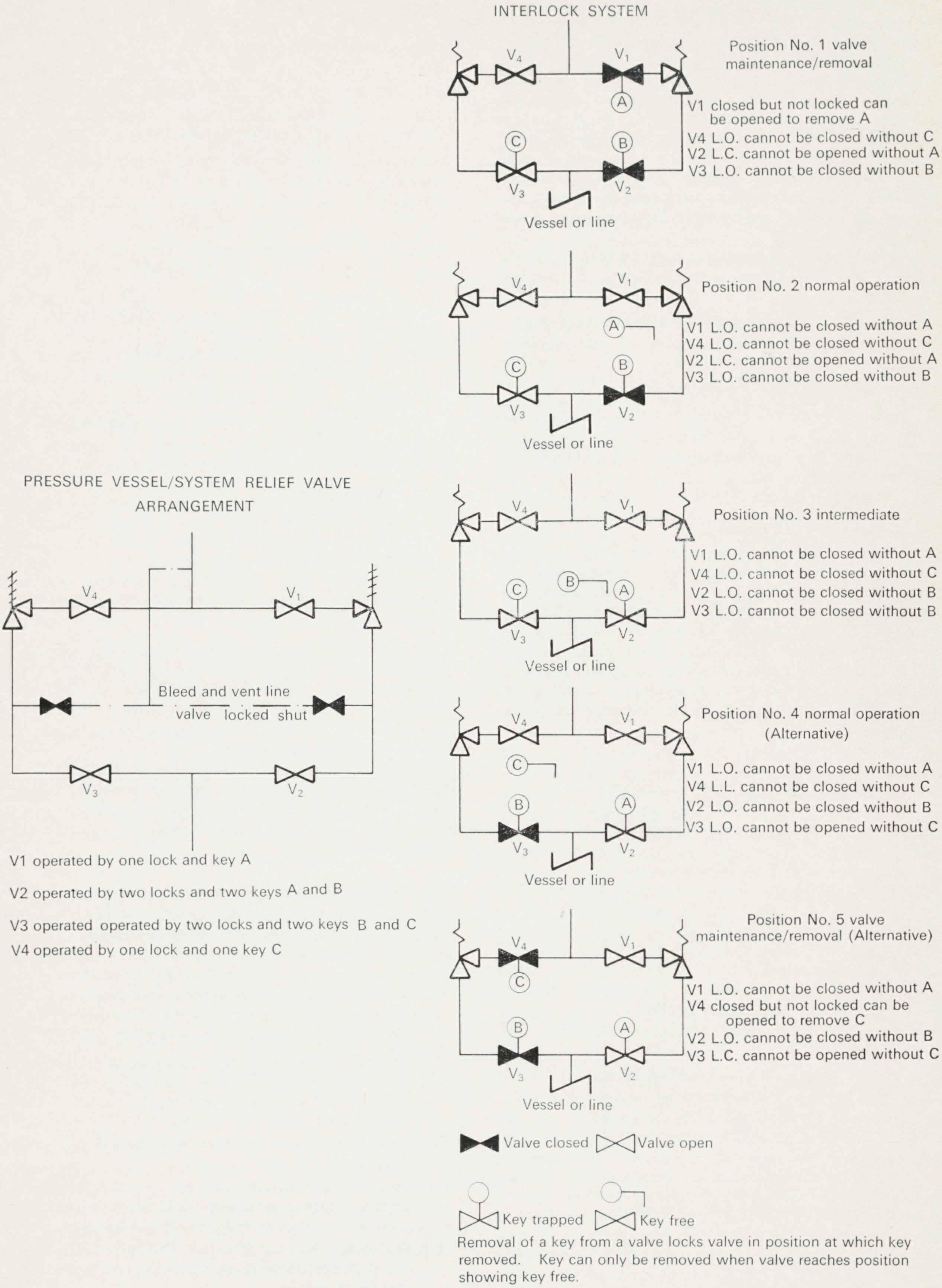


Fig. 49

Acceptable Interlock Arrangement (Safety Valves)

Gas turbine units are normally enclosed in acoustic hoods. Double casing of the piping within the hood/enclosure is not insisted upon due to the copious volume of air venting required to maintain the internal temperatures of the hood at an acceptable level. It is considered that in the event of failure of a pipe within the hood, any fuel gas released would be dissipated before an explosive condition could be reached, due to the cooling air drawn in and exhausted to a safe area. Gas, temperature and fire detector alarms are also to be provided within the hood, and the usual practice is that operation of any one device would initiate an alarm and operation of any two devices would initiate an automatic total flooding of the hood with inert gas and commence an automatic shut down sequence for the turbine.

Gas fuel piping without ducting can be accepted in way of safe areas, provided the following requirements are complied with:—

(i) The pipes are of heavy gauge and with welded joints.

(ii) There is adequate ventilation with not less than 10 changes of air per hour.

(iii) Gas detectors are provided in the safe space.

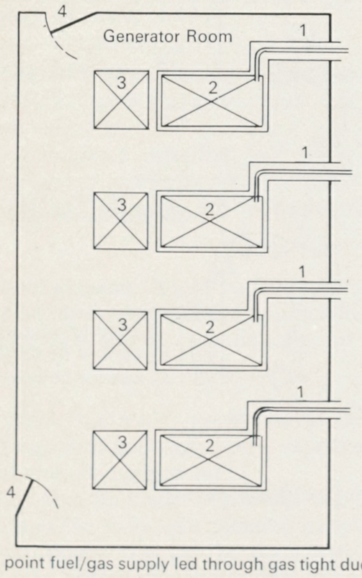
(iv) Valves, regulators, etc, are not located within the safe space.

Figures 50 and 51 indicate acceptable arrangements for low flash oil/gas fired units.

11.4.2 Oil and Gas Fired Boilers

These should not be located in hazardous areas.

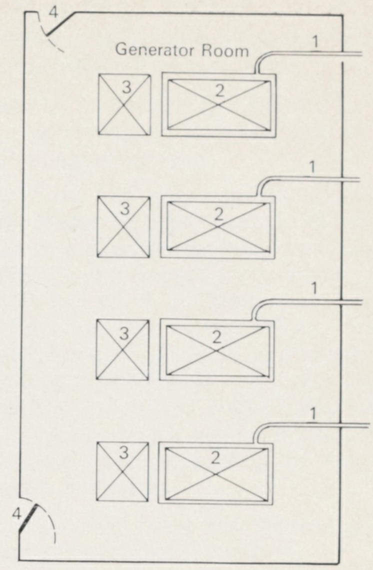
It is appreciated that such items a glycol regenerators and fuel gas heaters are usually located in freely ventilated spaces on the open deck within the gas/oil production complex, and are part of these systems. In view of this it is usual to require the combustion air for these units to be taken from a safe area. Alternatively, the air intakes are to be fitted with efficient flame arresters for which details and documentation of acceptance by a national/acceptable authority are to be provided.



1. Low flash point fuel/gas supply led through gas tight duct.
2. Prime mover located within gas tight hood/shroud
3. Electric generator
4. Access from safe space

FIG. 50

Acceptable Arrangements for Gas (Fuel) Fired Power Units



1. Low flash point oil/gas fuel led through all welded pipe of heavy construction
2. Prime mover located within gas tight hood/shroud
3. Electric generator
4. Access from safe space.

FIG. 51

Acceptable Arrangements for Gas (Fuel) Fired Power Units

It should be noted that sour crude oil can liberate hydrogen sulphide, which is highly toxic and can be lethal if inhaled. Classification of physiological responses to various concentrations of H_2S have a scale range from (1) for short term exposure to (6) for immediate threat to life, with 2 ppm and 1000 to 2000 ppm, respectively.

Institute of Petroleum 'Model Code of Practice' 1972, Part 8, Section 9, Paragraph 9.3 advises that personnel carrying out work, such as dipping tanks or entering areas where gas may be encountered, should always be accompanied by a second person.

11.5 Submersible Units and Systems

The Rules for Submersibles, published in 1973, cover such items as diving bells, diving suits, decompression chambers, and submersible units for underwater survey and inspection. Piping systems for the submersible units are also dealt with and the following points should be considered:—

(i) Ball valves should NOT be fitted in oxygen systems other than as emergency shell/shipside shut-off valves.

(ii) Piping systems are to be of approved metallic construction and suitable for the intended service. (In this respect stainless steel is not recommended for use in oxygen systems.)

(iii) Sharp bends are to be avoided in all high pressure systems.

(iv) Flexible pipe lengths are to be restricted to short joining lengths, and are to be of approved type and of material compatible with the service intended.

(v) Shell/shipside shut-off valves should be fitted direct to the shell or, alternatively, if this is not practicable, to short stub pieces.

(vi) Ball valves, if fitted within submersible units, are to be provided with positive locking in open and/or closed positions.

(vii) Couplings are to be of an approved type. (It will be appreciated that the size of the piping in the life support system is restricted to small diameter, e.g. 6 mm, 12.5 mm and 25 mm tubing, and screwed couplings are extensively used in these systems.)

(viii) Two means of life support are to be provided, and the arrangements are to be such that failure of one supply does not render the total life support system inoperable.

(ix) Helium gas systems are to be arranged so as to prevent contamination of the breathing mixtures due to leakage. A suggested arrangement is to provide two isolating valves with a drain valve between.

(x) Where heating for the divers is essential to life support, two means of heating are to be provided.

11.5.1 Umbilical Hoses

Rules are currently being formulated for umbilical hoses, and at present it is usual to require the hoses to be of an approved type for essential services in marine use.

11.5.2 Ballast System

May be fixed or variable. Variable ballast comprises, usually, of main and auxiliary ballast and, if fitted, a trim system.

It should be noted that air can be used for displacing water down to a depth of about 617 m, but at greater depths air becomes more dense than water and so cannot be used.

Whilst no objection is seen to the variable ballast/trim systems, it is considered that standby pumping arrangements should be provided for these systems and for the trim system. The ballast transfer systems may be operated by normal pumping systems or air displacement systems. However, because of the importance of this system, a high reliability is required of the main and standby systems.

11.5.3 Life Support Systems

The purpose of this system is to provide breathing gas adequate to support the life of those personnel on board. The capacity of the life support system will require careful consideration having regard to the maximum anticipated duration of the submerged operation. Consideration must also be given to the capacity of the emergency life support system.

The storage capacity for the oxygen system should be on the basis of maximum duration (time) and based on 0.028 m^3 (28 litres) of oxygen per crew member per hour. It is understood that the 'average' man consumes about 0.025 m^3/hr (25 litres) and 760 mm Hg and 21°C.

When designing such a system, consideration should be given to the fire hazard incurred when the oxygen concentration increases to above 21% by volume. As oxygen pressures increase, materials which are normally considered fire proof become combustible. With oxygen-enriched systems, all the conditions for fire exist within the system itself, e.g.

(i) The system fluid/gas acts as the oxidizer.

(ii) Fuel is provided by the system component material.

(iii) The source of ignition/heat can be obtained from various causes, e.g., adiabatic compression, in which heat is generated by the high velocity of gas due to too rapid an opening of valves in high pressure systems; static; impact by small particles of bulk system; and ragged edges of pipe or valves which may cause hot spots.

To obviate the above sources of heat it is considered that valves in these systems should be of the screw lift, slow opening type, with the possible exception of emergency shell/shipside shut-off valves. Ball valves should not be fitted. Sharp bends should be avoided, pipes should be cut with suitable pipe cutters, not hacksawed, and the ends trimmed and smoothed. Storage quads for oxygen systems are to be located on the open deck or in a well ventilated compartment. Gaseous oxygen is usually stored external to the command module in steel containers, and these are constructed in accordance with the requirements of the national authority with which the submersible is registered, e.g. in the United Kingdom the Home Office Requirements. These bottles will normally be stored within the fairings between the command module and the machinery module, and it is considered the system should be divided into 'banks' and so arranged that failure of the system in one bank, due to damage of the piping or storage bottles, would not result in loss of life support from the other banks. Similar arrangements are to be provided in the case of submerged diving chambers (diving bells).

Each bank should have its own independent charging line fitted external to the command module. Valves in these systems should be of an approved material compatible with oxygen or oxygen/helium gas. Provision should be made for indicating O_2 and CO_2 within the command module and also the pressure in each storage system. Independent quick shut-off valves should be provided at the shell penetration for each oxygen bank, and an isolating valve of S.D.N.R. type fitted inboard of the pressure gauge.

Pressure-indicating devices should be provided before and after any pressure-reducing arrangements. Where automatic controls are to be provided provision must be made for indicating failure to the crew and manual operation of the system should also be available.

Piping is to be of an approved metallic construction compatible for use in oxygen and, or, oxygen/helium gas. Where flexibility is essential, e.g. between permanent piping systems and items of machinery, flexible pipe lengths of approved armoured material may be accepted provided the flexible pipe is kept as short as practicable and there are properly attached end fittings of the crimped or swaged type. The piping is to be suitable for the maximum pressure to which it may be subjected. Piping should be adequately supported and anchored and also protected against mechanical damage. Where screwed fittings are provided they should be of an approved type, and provision made to prevent slackening back due to vibration or other causes. Where 'Teflon' tape is used in conjunction with pipe threads, care must be taken to ensure that the 'Teflon' does not enter the pipe system due to the possibility of stripping and thereby interfering with the natural flow of gas by blocking the pipe or valves. For this reason the 'taping' of the threads should be restricted to the last three or four threads on the coupling. After assembly, the system will require to be tested hydraulically to not less than 1.5 times the maximum working pressure, after which, it will be necessary for the system to be dried out and leak tested to not greater than about 1.25 times the working pressure.

11.5.4 Emergency Release Systems

The sole purpose of this system is to ensure surfacing in the case of emergency by either inflating external tanks, or alternatively, by releasing ballast weights or equipment, thus giving positive buoyancy to the vessel. For small submersibles used for scientific purposes or in conjunction with underwater surveys/retrieval systems, this is usually arranged by way of a hand operated hydraulic system, by which means it is possible to release external equipment such as battery pods, ballast weights, propulsion units and, where fitted, operational items such as manipulators (claws).

There should be some indication of the operation of the relieving device, e.g. a pin, if this cannot be verified from the command module. Emergency release systems must have a high reliability and are to be capable of manual operation.

11.5.5 **Heating Systems**

Low temperature can have serious effects on divers, and therefore, consideration must be given to the need for diver heating. It is the Author's opinion that such systems are essential, especially when used in conjunction with deep diving operations employing oxy-helium environments and breathing mixtures, and it is considered that two means of heating should be provided.

In this respect it may be well to draw attention to the following:—

(i) Low temperature—hypothermia—can cause amnesia, cardiac irregularities and increased oxygen intake.

(ii) Divers operating in a helium environment lose body heat through exhaled gas from the lungs as well as through the skin.

(iii) Ideally a diver operating under the above conditions should be provided with inhaled gas heating in addition to body heating.

(iv) CO_2 retention can also be caused by cold and lead to unconsciousness.

CONCLUSION

In compiling such a paper as this, the difficulty has been not so much in commencing, but in stopping. The Author is very conscious of the fact that much has been omitted that possibly others would have considered justified inclusion. However, the paper has been written on the basis of plan approval, as dealt with in Head Office, and it is the Author's hope that it will prove to be of some assistance to members of the Technical Association.

ACKNOWLEDGEMENTS

The Author wishes to thank colleagues in the various departments in Head Office and outports for their advice and assistance, and in particular, Mr. H. R. Clayton, Principal Surveyor now retired, for his permission to use those parts of his paper considered still applicable. The Author would also like to thank Mr. G. Pumphrey for the preparation of the various diagrams included in the paper.

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APPENDIX I

SURVEY OF PUMPS

The Society has no requirements relating to the design of centrifugal pumps for marine service other than that, if employed on bilge duty, they should be of self-priming type or be capable of being primed by an approved priming device.

Pumps which are intended for bilge, ballast, oil fuel transfer and any other service essential to the propulsion of the ship or its safety, should be surveyed during construction by the Society's Surveyors, who are required to witness the hydraulic and running tests which are normally carried out. In the case of the hydraulic tests the practice varies, but it is considered that the test pressure should be not less than 1.5 times the working pressure. For refrigeration purposes a capacity test is also required on each size of pump.

The material of the pumps need not be tested in the presence of the Surveyors, but the Surveyors are required to satisfy themselves that the material is sound and suitable for the purpose intended.

If the Surveyors have any doubts regarding the suitability of pumps for bilge service, it will be necessary for tests to be carried out to demonstrate the efficiency of the priming devices and that the pumps can deal with water containing foreign matter such as is normally found in ships' bilges. During these tests, the suction line to the pump should be fitted with a mud-box or strainer of standard marine design, and with at least one non-return valve fitted in the line in order that the conditions may approximate to those prevalent on board ship.

A flexible suction pipe should be provided on the inlet side of the mud-box. In order to prove the pump's self-priming capabilities, whilst the pump is running at full power, the suction pipe should be lifted clear of the liquid and then replaced. This operation should be repeated several times.

Pumps not required for essential services such as washing water, drinking water and sanitary pumps need not be constructed under survey unless specially desired.

APPENDIX II

INERT GAS SYSTEM

Scope of Survey of Various Items

It is considered that the scope of the Survey should be as follows:

Item	*Survey No.*
Scrubber	7
Deck seal	7
Heating coils	5
Starters	6
Blowers (complete)	2
Scrubber water supply pump: motor	2
pump	6
Valves, shipside	1
Valves, other than shipside	6
Main gas control	6
Blower isolating	6
Deck isolating	6
Re-circulating	6
Boiler uptake valves with fail safe gear etc.	6
Main panel assemblies	1
Expansion bellows	5
Non-return valves	6
Gas temp. probe	
O_2 Indicator	
O_2 Analyser	4
Pass switch	
Press transmitter	
Press controller	3

The Survey number opposite each item indicates the Survey required, viz:

1 To be made under survey.

2 To be made under survey if more than 75 kW. Works test certificate if under 75 kW.

3 Works test certificate and environmental test.

4 Environmental test.

5 Hydraulic test.

6 No survey required.

7 Survey after installation only, unless specially requested.

The above refer to inspection at the manufacturer's works only. It will be necessary for the plant to be installed on board the ship and tested under working conditions to the satisfaction of the Society's Surveyors. A test schedule for the system should be forwarded in due course in order that it might be recorded that the Surveyor has witnessed satisfactory operation of the system.

If blowers are driven by steam turbines or gas turbines, either as a separate gas turbine unit or as part of a gas turbine generating set, and the power exceeds 110 kW, the turbines should be made under survey in accordance with the relevant sections of Part 5.

For powers under 110kW, the turbine casing pressure test and a full load test of the complete unit, including overspeed and safety cut-out tests, should be witnessed. In addition, manufacturers' test certificates for the materials of the turbine rotor and blading should be provided.

APPENDIX III

FLEXIBLE EXPANSION PIECES

In order to comply with Chapter 13, 2.1.3, heat sensitive materials should not be used in bilge, ballast or cooling water systems. With reference to cooling water lines, Chapter 13, 2.8.3 makes allowance for the use of expansion pieces of an approved type incorporating special quality oil resistant rubber or other suitable synthetic material, subject to the relevant requirements being complied with.

Further, Chapter 14, 4.5.1 and 4.6.1 require that pipes conveying oil fuel be of steel or other approved materials. Chapter 6, 1.7 also requires that pipes conveying oil are to be of an approved material, having regard to fire risk.

Flexible Hose

Flexible hoses are acceptable as short joining lengths between various items of machinery and permanent piping systems in positions where flexibility is essential, e.g.:

Fresh and Salt Water Cooling Systems

Synthetic rubber hose with cotton, or similar integral braided reinforcement, may be used. In the case of salt water pipes where failure of the hose could give rise to the danger of flooding, the hose should be protected as required by Chapter 13, 2.8.3.

Fresh and Salt Water, Fuel Oil, Lubricating Oil, Compressed Air, Bilge and Ballast Systems

(i) Synthetic rubber hose with single or double, closely woven wire integral braided reinforcement, is acceptable. In the case of oil fuel supply to burner, the hose should have external wire braided protection in addition to the integral braid.

(ii) Convoluted metal pipe with wire braid protection is acceptable (subject to approval of the method of construction and attachment of end fittings).

The hoses are to be examined by the Surveyors and be hydraulically pressure tested in their presence. Hose clips are not, in general, considered a satisfactory method of attaching hoses to end connections. This method of attachment is only acceptable where the hose consists of a short straight length, joining two metal pipes between two fixed points on the engine, and then on only the cooling water system, with two (2) hose clips at each end. In all other cases where flexible pipes are used in cooling water systems, the hoses could be accepted with flanges vulcanized on to the pipes, provided that metallic backing rings are fitted.

For oil, compressed air, bilge and ballast systems, the hoses should be supplied with properly attached end fittings of swaged, crimped or similar type.

Whilst such hoses are acceptable to the Society, as stated above, it will also be necessary for them to be acceptable to the national authority of the country in which the ship is registered.

Further, it must be added that:

Regulation 18-h (2) of S.O.L.A.S 1960 requires bilge pipes in boiler or machinery spaces to be of steel or other approved materials. Also, Regulation 54 (g) requires that pipes conveying oil or combustible liquids shall be of a material approved by the administration, having regard to fire risk. A similar wording is used in paragraph 18 (2) of the Merchant Shipping (Cargo Ship Construction and Survey) Rules 1965. S.A.F.C.O.N.

Exhaust Systems

Flexible metallic hose with copper or asbestos packing may be necessary for this application.

In the case of yachts or similar small craft, flexible hose of reinforced synthetic rubber construction can be used with water cooled exhaust systems.

APPENDIX IV

RESILIENT SEATED VALVES

These valves have either a liner or sealing ring of synthetic rubber or similar material to ensure tightness. All these resilient materials are to some extent heat sensitive and, accordingly, the valves have only been accepted by the Society for the following services:—

1 Shipside valves.

2 Salt and fresh water cooling systems.

3 Water ballast and fresh water pumping systems.

4 Cargo oil lines on tankers.

5 Bilge suctions for cargo holds in bulk carriers, but only when fitted in a pipe tunnel and in association with a metal seating non-return valve.

6 Suction valves on double bottom oil fuel tanks, but only when located in a closed pipe tunnel or duct keel.

7 As pump suction valves on the main bilge line, but only where the valve is located in the immediate vicinity of the pump. The valve to be fitted in conjunction with a metal non-return valve which is to be on the bilge main side of the butterfly valve.

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Lloyd's Register Technical Association

Discussion

on

Mr. J. Crawford's Paper

A GUIDE TO PUMPING AND PIPING ARRANGEMENTS

Paper No. 1. Session 1978-79

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

Hon. Sec. D. T. Boltwood
71, Fenchurch Street, London, EC3M 4BS

Discussion on Mr. J. Crawford's Paper

A GUIDE TO PUMPING AND PIPING ARRANGEMENTS

CONTRIBUTIONS

From Mr. E. Howey:

In this day and age when we have so many groups of people making and up-dating rules and regulations it is indeed refreshing to have such splendid evidence and detail—as Mr. Crawford has presented to us in his Paper this evening—of Lloyd's Register's Rules having so ably withstood the test of time. If only it were easier to get implementation of such rules and requirements, our daily tasks would become a little less difficult.

Yet no rule can regulate carelessness and we must continually be on our guard against mishaps. It would appear that we are in an age when human error is often discounted and we are forever searching into possible deficiencies of equipment and components in an endeavour to apportion blame in their direction.

Mr. Crawford's Paper gives good detail of many areas in which "Pumping and Piping" play a vital role, perhaps the most important role, especially in oil, gas and chemical tankers. I suggest that his Paper will prove to be a useful and ready guide and reference for each one of us.

Finally, and as briefly as possible, I would ask Mr. Crawford to comment on the following: —

1. Should large diameter sea connections have remote control capabilities or extended spindles?
2. Should main pump-room sea-valves be duplicated to form an inner and outer valve?
3. With inert gas systems, where a closed ullage system is demanded, how does the ship's staff check the inerted cargo tank remainders, or whether the tank is in a dry condition?

From Mr. B. W. Oxford:

It is obvious that Mr. Crawford has burned a considerable amount of midnight oil in preparing this comprehensive and informative paper and since I am sure that none of you are prepared to burn midnight oil listening to my comments, I shall be reasonably brief.

It is also obvious from the length of this Paper that there is a substantial amount of pumping and piping in this world and it is just as well that the Society calls only for diagrammatic plans.

As Mr. Crawford has explained, these plans vary greatly depending on the experience and quality of the Shipbuilder's draughtsmen. In some cases considerable satisfaction can be gained by sorting out the pipelines on the plan. In other cases we may feel slightly uneasy because we can find nothing wrong and we are left wondering if something has been overlooked.

Pumping and piping does not pretend to be an exact science but there is a certain art, almost intuitive at times, in examining plans which give an overall picture of a new ship and the piping systems on board. This bird's eye view of the ship is, perhaps, one which the outdoor surveyor cannot have in his mind since he can only be in one spot at one time.

I think that we inside Head Office have to appreciate the world of the Surveyor outside, where he may be confronted with a problem or object requiring immediate attention. Similarly, we hope that the outside Surveyor will appreciate our viewpoint which, of necessity, has to rely much more on memory and imagination. A sketch is often much more helpful to us than words.

I am glad that in this Paper Mr. Crawford has made liberal references to the Rule numbers, which saves a lot of searching for most of us, and that in one or two places he has stated the original intention of the Rules. I think it is important that the Rules should be emphasised and not the exceptions.

Rather than make comments on points which may be repeated by other colleagues my remarks, up to now, have deliberately been of a general nature and I do not intend to make any individual comments except on one item. This concerns Part 5, Chapter 15 of the Rules paragraph 4.2.4 which states that means are to be provided to prevent any tank being subjected to excessive pressure or vacuum during any phase of cargo handling or ballasting operations. Unfortunately, but for valid reasons and as Mr. Crawford has also mentioned in his Paper, Part 5, Chapter 15 4.2.4 and Part 5, Chapter 15 7.6.5 also state that means are to be provided for isolating either the vent main or inert gas main, which are often combined, from each cargo tank. This means that in certain circumstances a cargo tank can become completely isolated from the possibility of either venting an overpressure condition or sucking in air in an underpressure condition, as a last resort before tank rupture occurs. The pressure/vacuum breaker in the inert gas main, referred to in Part 5, Chapter 15 7.6.4, does not protect the tank if the tank has been isolated from the main. In such circumstances the Surveyor should be assured that alternative pressure/vacuum arrangements are available on board, such as portable P/V valves which can be attached to the isolated tank, or other suitable arrangements.

While the above mentioned paragraphs refer in particular to tankers, the same hazards could apply, for instance, to a floodable hold in a bulk carrier and each case should be carefully considered.

In conclusion I wish to thank Mr. Crawford for this bold and interesting Paper which is a worthy successor to the "Pumping and Piping" Paper published by Mr. Clayton in 1960.

From Mr. R. Gardiner:

I would like to offer my congratulations to Mr. Crawford on the presentation of his Paper. As this latest Paper on pumping arrangements comes at a time when we are all acquainting ourselves with the new 1978 Rules, the relevant paragraph numbers should greatly assist Surveyors engaged in either plan approval or in the "field".

I would like to amplify a few specific points as follows:

Tank Suction Filling and Air Pipes (paragraph 3.3, page 2)

Reference is made to air pipes from cofferdams and void tanks. The question of ventilation is particularly important in vessels such as pontoons and barges. In many cases, usually at the Owner's request, there are no air pipes to the void tanks of these vessels so as to keep the deck clear for cargo. As far as unmanned barges and pontoons are concerned, portable pumps carried on board with suction hoses have been accepted for drainage of void tanks through the manholes, provided a suitable notice is fitted to the manhole covers stating that the tanks are to be adequately ventilated and found gas-free before entry.

Flooding of Holds (paragraph 3.10, page 9)

The practice of flooding holds is quite common in bulk carriers these days and is mentioned in the new Rules (Part 5, Chapter 13, 3.3.1, and 3.3.2) as far as pumping and piping requirements are concerned. The main items are the blanking arrangements, i.e. the bilge suction blanked off when carrying water ballast and the water ballast connection blanked off when carrying dry cargo.

Remote Control Valves (paragraph 4.2.1, page 12)

The requirements for hand pumps where used as the secondary means of operating remote controlled valves are stated. It might be mentioned in regard to shipside valves that a hand pump would also be acceptable provided a pump is fitted permanently connected ready for immediate use to each valve. The Society's Rules at present do not require remote controls for shipside valves.

However, certain National Authorities may have requirements. In this respect it may be worth noting that for Norwegian Flag ships which have unattended machinery spaces, the Norwegian Maritime Directorate require remote controls for main auxiliary sea inlets and discharges. Remote controls may be omitted if the pipe systems consist of pipes of substantial thickness or corrosion resistant material which have been approved by the Maritime Directorate or the relevant Classification Society.

Starting from Cold (paragraph 4.11.4, page 24)

It might be handy here to note that in addition to the examples given, that a device for first starting by means of the impulse provided by burning a strip of film in one cylinder of an engine (e.g., the "HANSA" starter) have now been accepted. I mention this as at the time of Mr. Clayton's Paper it was stated that such devices were not acceptable as an alternative to hand start arrangements. The conditions under which this type of starter may be accepted are given in Instructions to Surveyors, Amendment No. 10, Part 26, 1956 dated 10th June 1975.

Location of Cargo Tank Vents (paragraph 5.1.6, page 26)

In regard to the height of vents as shown in Fig. 27 it might be borne in mind that whilst an open vent at a height of 4 m above the deck or gangway satisfies the Rule requirements in principle, on modern tankers this would be rarely used, if at all. Over 100,000 tonnes DWT a tanker, to comply with the Rules, requires an inert gas system to be installed which would require a closed type venting system i.e. P/V valves and/or high velocity vents.

Container Ships (paragraph 8.3, page 39)

The Author states that in his opinion bilge and ballast valves may be located in cargo holds provided a class notation is assigned to the ships "Holds Limited to Container Cargoes". I think here we could definitely state that the Society has accepted such an arrangement. There are a number of ships with this notation (e.g. *DART AMERICA*, *DART ATLANTIC* and *DART EUROPE*, to mention three) the class limitation being imposed solely because of the location of bilge and ballast valves in the holds. I personally do not think it is a system to be recommended and unless the ship has a duct keel in which the valves can be located and are accessible. I would prefer to see the valves located in the machinery space.

There is another point that may be worthy of consideration. One would imagine that Owners these days with too many ships chasing too few cargoes would prefer some flexibility with their ships (e.g. we now have the Multi-Flex ship for general cargo, containers, Ro-Ro, bulk, etc.) Only recently we have received in Head Office an enquiry from an Owner of a container ship with a request that the class restriction referred to above be lifted to enable the ship to carry general cargo for a few voyages. The initial enquiry from the Owner had completely overlooked the fact that the bilge valves were located in the holds and for the class restriction to be lifted it would be necessary for the bilge valves to be removed from the holds and relocated in the machinery space.

From Mr. R. B. Siggers:

Mr. Crawford is to be congratulated on tackling the long overdue job of revising Mr. Clayton's Paper.

Since Mr. Clayton read his Paper almost twenty years ago, we have seen very many changes in sizes and types of ships and one of the biggest problems for Mr. Crawford must have been deciding what to include and what to leave out. It seems he has achieved the right balance.

The decision to omit or include any item is necessarily a personal one and in this respect perhaps, I would not have included so much information on ballast/oil fuel changeover devices, cock chests and double bottom wing suctions since these arrangements are very rarely encountered nowadays.

The air pipe closing appliance shown on page 8 is an interesting one and in theory satisfactory. However my experience of these has revealed that they are frequently painted over and seized. The modern practice appears to make greater use of Weinel Type Ball vents and I wonder if a sketch of this type could be included in the written answer to the discussion.

With regard to the ballast suction valves fitted inside a tank which contravene Part 5, Chapter 13, 2.3.3 of the Rules, recent events have perhaps overtaken Mr. Crawford's Paper since we now accept the single valve, subject to the conditions indicated on Page 12 and do not now ask for two valves.

Perhaps Mr. Crawford could comment on whether, in his opinion, we should bow to the inevitable and delete the requirement on accessibility from the Rules?

Finally, I would like to ask Mr. Crawford's opinion regarding dropping valves for topside tanks on bulk carriers. Part 5, Chapter 13, Paragraph 3.1.1 requires provision to be made for *pumping out* any tank or space. Does this dropping valve constitute *pumping out*, since the bottom of the tank could be submerged in certain conditions?

From Mr. P. Holbrook:

As the Author rightly states, we have seen the emergence in recent years of highly specialised ships and this has led to some new and interesting pumping and piping arrangements. My remarks are confined to Section 7, Fuel Gas and Crude Oil Burning and Section 11, Offshore Services.

Section 7. Methane Fuel Gas Burning

While the Author has given a concise description and sketch of the arrangements for burning methane in boilers, there does not appear to be any mention that the Rules also cover the use of such boil-off in oil engines. Many of the requirements are the same but perhaps a few comments on gas supply pressures for the various applications would be beneficial and, in particular, the Author's opinion on pressure drop which could be experienced, say, in a 1 Kg/cm^2 boiler supply pressure.

Methane in its commercial state has a specific gravity of about 0·506; would the Author care to state why the Rules have limited gas burning to Methane and whether he is in favour of allowing gas mixtures with a specific gravity not exceeding, say, 0·9 to be used?

With regard to the comments on dump condensers for burning boil-off in port, the Paper suggests that a separate

boiler/dump condenser is fitted, but surely there would be no objection to using the normal ship's boilers and utilizing the steam through an alternator with a dump condenser as an alternative. With oil engined ships perhaps incinerators would be a viable alternative for in-port boil-off.

7.2 Crude Oil Burning

As the Author implies, we have no published Rules at present for the burning of crude oils although there has been an upsurge of interest recently, particularly in relation to offshore oil storage tankers.

Referring to Fig. 41

1. It is essential that the pipe casing should be arranged to slope naturally towards the pump room bulkhead so that any leakage can be drained into the drain tank.
2. Even though the pipe casing extends very near to the burners, IACS requires that burner trays are provided with drains led back to the drain tank.
3. Should there not be some means of purging the pipelines into the drain tank for maintenance purposes?
4. A burner steam atomizing arrangement is shown, however: —
   - 4.1 Certain authorities now prohibit the use of atomizing steam with light oils and insist that compressed air is used.
   - 4.2 No steam or air purging connections are shown although the valve arrangements for this are quite complicated and perhaps it would be possible to include a more detailed sketch showing the burner arrangement.

While on this subject it is interesting to note that the Author states that the pump room fans have to be interlocked with the crude oil pumps. IACS requires the boiler hood extraction fans to be interlocked with the crude oil system and also states 100% standby fan capacity. Perhaps the Author would comment on this point?

Secton 11. Offshore Services

The Author's involvement with the pumping and piping systems relating to Offshore Services is well known and it may even be said that MDAPAD's efforts in this respect are as a result of his work.

Production platforms and gas/oil systems are extremely complex and when looked at against the comprehensive way the corresponding ship systems have been dealt with, are bound to give the impression that our work is conducted at an ineffectual level. For instance paragraph 11.2.2—spark arresters. Gas turbines apparently do not require these to be fitted but it is considered essential that some means is provided to prevent the emission of sparks. Perhaps the Author would care to clarify this point?

Paragraph 11.2.4

While oil engines are required to be provided with a device to prevent over-speeding due to the ingestion of gas, one is led to believe that because this is not practical for gas turbines that they are excluded. Would the Author agree that they are not necessary because the blade efficiency of a turbine would make overspeeding unlikely or even impossible?

Paragraph 11.4.1

Is it correct to say that gas turbines cannot be located in hazardous areas?

Paragraph 11.4.2

I cannot quite understand the relationship between oil/gas fired boilers and hydrogen sulphide unless it is meant to imply that heated crude oil liberates a greater quantity of gas. However, if sour crude does exist it will release hydrogen sulphide whether it is heated or not.

From Mr. C. Campbell:

I would like to raise the following points: —

Section 11.2—Fixed Platforms

Is it to be understood that all major machinery items and pressure vessels be constructed under survey in same manner as for ship classification?

Since the fire fighting systems and equipment are critical to safety on the platform, the operating personnel will be taking the efficiency of such systems for granted. Therefore the subtle difference between "LR inspected" and "constructed to National standards etc." is not understood, or do we consider that platform safety is less important than on board ship?

It is current practice in Offshore Services *not* to inspect electrical equipment at source but accept a presentation of adequate documentation at the installation stage say on a module site or offshore.

Section 11.3—Gas and Oil Production Systems

(i) At what stage is the suitability of materials for valves, pipes and fittings considered by MDAPAD when appraising plans for D.O.E certification? Do MDAPAD assume that the inspection standards for such items are equivalent to marine requirements?

(ii) Please comment on approved type of valves and in particular what are the Society's requirements for a fire safe valve and in particular, how is the valve size chosen from a range of sizes?

(iii) Comments would also be appreciated on the use of relief valve locking and isolating systems (Fig. 49), from the point of view of the Operators' responsibility in their use and maintenance.

(iv) Is the present method of approving pressure system line diagrams for D.O.E certification considered to be adequate with respect to the overall safety of the installations?

In conclusion I wish to thank the Author for producing such an interesting paper.

From Mr. R. J. Hook:

I would like to congratulate Mr. Crawford on a most informative, and comprehensive Paper which will be a valuable addition on this subject to the Transactions of our Association. He follows in the footsteps of Mr. John Beveridge and Mr. Harold Clayton both of whom presented Papers on pumping and piping arrangements in the 1938/9 and 1959/60 sessions respectively.

Mr. Crawford will know that just about the highest compliment I can pay him is to say that I am sure that in the years to come his Paper will be of equal value and appreciated and prized in exactly the same way.

On coming to Mr. Crawford's Paper itself and referring to Fig. 12, page 13, it may be helpful to add that it is due to the onset of cavitation with increase in temperature of the liquid that the lift of a reciprocating pump is governed in the way shown in the figure.

The Author's use of the word "size" may be found by some to be a little confusing since it may be misread as meaning "area" whereas in fact it is the diameters of the relevant pipes which are under discussion in paragraphs 4.1 and 4.8.1 and is the term used in the Rules.

With reference to the so called calculation sheet shown

on pages 4 and 5, a more accurate description might be "piping system record sheet", since the amount of calculation on it is minimal and restricted to a few square root functions to determine the Rule diameters of main and branch bilge suction pipes. It would be interesting if the Author would give some indication of the source of these formulae and how they came to be derived.

With reference to the "C" value given for the length of the machinery compartment, it would appear that a slight printing error has occured. This should read 12·95 and not 129·5 as shown. In Fig. 11 the figure of 4·3 given would also appear to be a misprint. This should be 4·63, but preferably, to be consistent with the present Rules Part 5, Chapter 13 5.2.1 should be expressed as 2,15 outside the square root sign. This is, of course, quite a minor point but should be taken note of and corrected for the sake of accuracy.

With regard to the section on Inert Gas Systems on page 32, reference is made to pipes of substantial thickness not less than 12·5 mm thick. In these metric days in which we live one wonders whether this figure could not be conveniently rounded up to some practical metric value, it being realised, of course, that what is being quoted here is the old Imperial ½", but presumably this is by now disappeared in the pipe manufacturing industry.

With reference to paragraph 4.10.5 and crankcase vent pipes, it may be helpful to add, for multi-engined installations, vent pipes, if fitted, are to be independent to avoid communication between crankcases. Similar requirements also apply to lubricating oil drain pipes from an engine sump to a drain tank and reference should be made to the Rules Part 5, Chapter 2, Section 4 in the above connection.

A very useful addition to this Paper would be to include lists of approved ball and butterfly valves and flexible hoses, and perhaps the Author could give some consideration to this on the lines of the list of types of approved control and electrical equipment, published by the Society in 1977? During my time doing machinery plan approval work on the N.E. Coast, such lists were in fact prepared and circulated on a local basis and it is believed were found helpful by the Surveyors concerned.

Whilst referring to flexible hoses would the Author advise as to what is meant by a "properly attached end fitting"? I am afraid this is something which has never been very clear to me.

With reference to paragraph 4.8.1 dealing with cooling water returns to sea inlets for Ice Navigation, one wonders as to the need and effectiveness of such connections, bearing in mind that the sea inlets may be 3 or 4 metres below sea level and for a ship to move through ice of such thickness it would presumably have to be an Ice Breaker rather than a ship having the notation "Strengthened for Navigation in Ice" whether it be Northern Baltic or Class 1, 2 or 3. Such ships navigate in broken surface ice conditions and so one is inclined to query the practical usefulness of these particular requirements and the conditions in which they would be used other than perhaps in an attempt to keep the inlets free from broken ice which may get drawn into the inlets by the pump suction.

In section 3.3 Mr. Crawford refers to the vital necessity for void spaces to be adequately ventilated and to the tragedy of a Surveyor losing his life by asphyxiation after entering a forepeak tank. In drawing attention to this fatal incident the Author has performed a useful service to us all, since knowledge of it could well save the life of anyone finding themselves in similar circumstances. So far as plan approval is concerned, we request that two air pipes be fitted to void spaces, as the Author indicates. However, should this not be ascertained at the plan approval stage, it is strongly recommended that Surveyors should make every endeavour to ensure that two air pipes are fitted to all void spaces. The importance of the above is self evident, having regard to the tragic consequences that can result.

Before closing it is interesting to observe that Mr. Crawford's fifty page Paper conveniently divides into two main halves, pages 1–24 and 25–50, the latter half consisting of most useful references to piping systems for types of specialised ships developed over the past twenty-five years or so and others of a more familiar type. The section dealing with Offshore Services is a most useful addition.

There is no doubt that in preparing and presenting this Paper Mr. Crawford greatly merits our hearty and grateful thanks.

As an appendix to my contribution to the written discussion it is hoped that the attached extracts from the 1978 Rules, Chapters 13, 14 and 15 may be found helpful. It is intended that these extracts shall offer a guide to the main subject matter of each of the relevant paragraphs of the 1978 Rules and to indicate to which paragraph further reference should be made. It is hoped it will be found useful, not only to Surveyors engaged on piping systems' plan approval work but also to field Surveyors engaged on new construction, conversion and repair work, or simply for verifying piping arrangements against Rule requirements as circumstances may require. To facilitate their use, the extracts are provided with columns headed "Complied With" and "Not Complied With" and these are intended to provide a "tick-off" facility which may be found advantageous when verifying piping arrangements.

BILGE DRAINAGE SYSTEMS

SHEET No.:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 5		
	Sizes of bilge suction pipes.		
5,13, 5. 1.1	Diameter of main bilge line.		
5,13, 5. 2.1	Diameter of branch bilge suctions to cargo spaces.		
5,13, 5. 2.1	Diameter of branch bilge suctions to machinery spaces.		
5,13, 5. 3.1	Diameter of direct bilge suctions.		
5,13, 5. 4.1	Diameter of main bilge line for tankers.		
5,13, 5. 5.1	Area of branch pipes connecting bilge main to suction distribution chest.		
5,13, 5. 6.1	Diameter of tunnel well bilge suction.		
	SECTION 6		
5,13, 6. 1.1	Number of bilge pump units.		
5,13, 6. 1.2	Number of pumps per unit.		
5,13, 6. 1.3	Bilge ejector and high pressure sea water pump.		
5,13, 6. 1.4	Number of bilge pumps for small ships.		
5,13, 6. 1.5	Number of bilge pumps for passenger ships.		
5,13, 6. 1.6	Location of bilge pumps on passenger ships —see 8.1.		
5,13, 6. 2.1	General service pumps used as bilge pumps.		
5,13, 6. 3.1	Speed of flow 122 m/min.		
5,13, 6. 3.2	Capacity of bilge pumping units.		
5,13, 6. 3.3	Deficiency in capacity of one bilge pumping unit.		
5,13, 6. 4.1	Pumps on bilge service to be of self priming type/central priming system		
5,13, 6. 4.2	Cooling water pumps having emergency bilge suctions.		
5,13, 6. 4.3	Emergency bilge suctions (see 4.6).		
5,13, 6. 5.1	Bilge pump connections.		
5,13, 6. 5.2	Connections to pumps required for essential services.		
5,13, 6. 6.1	Direct bilge suction connections.		
	SECTION 7		
5,13, 7. 1.1	Main bilge line suctions.		
5,13, 7. 2.1	Prevention of communication between compartments.		
5,13, 7. 3.1	Isolation of bilge system.		
5,13, 7. 4.1	Machinery space suctions—Mud boxes.		
5,13, 7. 5.1	Hold suctions—strum boxes.		
5,13, 7. 6.1	Capacity of bilge wells.		
5,13, 7. 7.1	Tail pipes.		
5,13, 7. 8.1	Location of bilge valves, cocks and mud boxes.		

BILGE DRAINAGE SYSTEMS

SHEET NO:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 7 (contd.)		
5,13, 7. 8.2	Relief valves on sea water pumps.		
5,13, 7. 9.1	Bilge suction pipes in double bottom tanks.		
5,13, 7. 9.2	Wall thickness of bilge pipes in double bottom tanks.		
5,13, 7. 9.3	Expansion bends on bilge pipes in double bottom tanks.		
5,13, 7. 10.1	Bilge pipes in way of deep tanks.		
5,13, 7. 10.2	Expansion bends on bilge pipes in deep tanks.		
5,13, 7. 10.3	Test for pipes after installation in tanks.		
5,13, 7. 11.1	Hold bilge non-return valves.		
5,13, 7. 12.1	Blanking arrangements for pipes in deep tanks and cargo holds.		
5,13, 7. 12.2	Oil fuel or cargo oil with F.P. $>$ 60°C in deep tanks.		
5,13, 7. 12.3	Blanking arrangement for cargo oil with F.P. $>$ 60°C.		
	SECTION 8		
	Bilge drainage and cross flooding on passenger ships.		
5,13, 8. 1.1	Location of bilge pumps and bilge main.		
5,13, 8. 1.2	One power pump to be available in all circumstances of flooding.		
5,13, 8. 1.3	Location of bilge main within B/5 line.		
5,13, 8. 1.4	Bilge pumps and pipes outboard of B/5 line.		
5,13, 8. 2.1	Prevention of communication between flooded compartments.		
5,13, 8. 3.1	Arrangement and control of bilge valves.		
5,13, 8. 3.2	Controls and indicators for bilge valves operated above bulkhead deck.		
5,13, 8. 4.1	Cross flooding arrangements.		
	SECTION 9		
	Drainage arrangements for ships not fitted with propeller machinery.		
5,13, 9. 1.1	Number and position of hand pumps.		
5,13, 9. 1.2	One handpump per compartment or alternative arrangements.		
5,13, 9. 1.3	Pumps to be worked from deck or above load line.		
5,13, 9. 1.4	Sizes of hand pumps as per Table 13.9.1.		
5,13, 9. 2.1	Drainage arrangements in ships with auxiliary power.		
5,13, 9. 2.2	Pumping arrangements to suit size and service of ship.		
5,13, 9. 2.3	Details to be submitted for special consideration.		

AIR AND OVERFLOW PIPES

SHEET No.:

PARA No.		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 10		
5,13, 10. 1.1	Cargo oil with F.P. > 60°C (closed cup test).		
5,13, 10. 2.1	Materials for pipes.		
5,13, 10. 2.2	Pipes above weather deck.		
5,13, 10. 3.1	Nameplates at upper ends of pipes.		
5,13, 10. 4.1	Air pipes to tanks, cofferdams, tunnels and other compartments.		
5,13, 10. 4.2	Position of air pipes.		
5,13, 10. 5.1	Termination of air pipes to D.B. and deep tanks.		
5,13, 10. 5.2	Termination of air pipes to lubricating oil storage tanks.		
5,13, 10. 5.3	Termination of open ends of air pipes to oil fuel and cargo oil tanks.		
5,13, 10. 5.4	Termination of air pipes on ferries—see Pt. 3, Ch. 12,3.		
5,13, 10. 6.1	Gauze diaphragms to oil fuel and cargo oil tanks.		
5,13, 10. 7.1	Air pipe closing appliances.		
5,13, 10. 7.2	Provision for relieving vacuum.		
5,13, 10. 7.3	Wood plugs and devices which can be secured closed.		
5,13, 10. 8.1	Size of air pipes.		
5,13, 10. 8.2	Air pipes to tanks fitted with cross flooding arrangements.		
5,13, 10. 8.3	Area of clear opening in wire gauze diaphragms.		
5,13, 10. 8.4	Air pipes to be not less than 50 mm bore.		
5,13, 10. 9.1	Overflow pipes to tanks which can be pressurised.		
5,13, 10. 9.2	Overflow pipes to oil fuel and lubricating oil tanks.		
5,13, 10. 9.3	Overflow pipes from tanks other than oil tanks.		
5,13, 10. 10.1	Arrangement of overflow pipes to be self draining.		
5,13, 10. 10.2	Arrangement of air and overflow pipes to prevent cross flooding.		
5,13, 10. 10.3	Overflows from oil fuel/water ballast tanks.		

CHAPTER 13 SHIP PIPING SYSTEMS

SOUNDING PIPES

SHEET No.:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 10 (contd.)		
5,13, 10. 11.1	Provision to be made for sounding all tanks.		
5,13, 10. 11.2	Sounding of compartments not readily accessible.		
5,13, 10. 11.3	Sounding pipes to be as straight as practicable.		
5,13, 10. 11.4	Sounding devices to be of approved type.		
5,13, 10. 11.5	Gauge glasses to be of heat resisting quality with S.C. valves.		
5,13, 10. 12.1	Termination of sounding pipes.		
5,13, 10. 13.1	Short sounding pipes in machinery spaces and tunnels.		
5,13, 10. 13.2	Short sounding pipes to oil fuel, cargo oil and lubricating oil tanks.		
5,13, 10. 13.3	Short sounding pipes to tanks other than oil tanks.		
5,13, 10. 13.4	Short sounding pipes in passenger ships.		
5,13, 10. 14.1	Elbow sounding pipes.		
5,13, 10. 14.2	Elbow sounding pipes to be of heavy construction.		
5,13, 10. 14.3	Elbow sounding pipes in passenger ships not permitted.		
5,13, 10. 15.1	Striking plates of adequate thickness.		
5,13, 10. 15.2	Slotted sounding pipes with closed ends.		
5,13, 10. 16.1	Sounding pipes to be not less than 32 mm bore.		
5,13, 10. 16.2	Sounding pipes passing through refrigerated compartments.		

OIL FUEL SYSTEMS

SHEET No.:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 1		
5,14, 1. 1.1	General requirements.		
5,14, 1. 1.2	Requirements of Ch. 13.3 applicable to drainage of tanks, oil bilges, cofferdams.		
	SECTION 2		
5,14, 2. 1.1	Flash point of oil fuel.		
5,14, 2. 1.2	Flash point lower than 60°C.		
5,14, 2. 2.1	Special fuels flash point below 43°C.		
5,14, 2. 2.2	Methane gas burning—see Rules for L.P.G. ships.		
5,14, 2. 3.1	Ventilation of spaces.		
5,14, 2. 4.1	Boiler insulation and air circulation in boiler room.		
5,14, 2. 4.2	Space between tank top and underside of W.T. boilers.		
5,14, 2. 4.3	Smoke box doors to be insulated and gas tight.		
5,14, 2. 5.1	Funnel dampers.		
5,14, 2. 6.1	Steam heating arrangements.		
5,14, 2. 6.2	Material of steam heating pipes.		
5,14, 2. 7.1	Temperature indication.		
5,14, 2. 8.1	Precautions against fire—location of tanks.		
5,14, 2. 8.2	Arrangement of oil fuel pipes clear of heated surfaces and electrical fittings.		
5,14, 2. 8.3	Arrangement and location of short sounding pipes to oil tanks.		
5,14, 2. 8.4	Water service pipes for sea water flushing.		
5,14, 2. 8.5	Use of wood to be avoided so far as practicable.		
	SECTION 3		
5,14, 3. 1.1	Number of oil burning units.		
5,14, 3. 1.2	Two unit installations—capacity per unit.		
5,14, 3. 1.3	Three or more units—capacities and arrangements.		
5,14, 3. 2.1	Duplex filters to be fitted in gravity feed systems.		
5,14, 3. 3.1	Starting up unit.		
5,14, 3. 3.2	Starting arrangements for auxiliary machinery for start up units.		
5,14, 3. 4.1	Steam connections to burners.		
5,14, 3. 5.1	Oil fuel burner arrangements.		
5,14, 3. 6.1	Quick closing master valve.		
5,14, 3. 7.1	Top fired boilers—flame failure.		
5,14, 3. 8.1	Oil burner spill arrangements.		
5,14, 3. 9.1	Isolating and interlocking arrangements for composite boilers.		

OIL FUEL SYSTEMS

SHEET No.:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 3 (contd.)		
5,14, 3. 10.1	Oil fuel filters in supply lines to main and auxiliary engines.		
5,14, 3. 11.1	Oil fuel booster pumps and stand by arrangements.		
5,14, 3. 11.2	Stand by booster pump.		
5,14, 3. 12.1	Fuel valve cooling pumps.		
5,14, 3. 13.1	Oil fuel tank for oil fired galleys.		
5,14, 3. 13.2	Location of fuel supply to oil fired galley.		
5,14, 3. 13.3	Ventilation of oil fired galley.		
	SECTION 4		
5,14, 4. 1.1	Transfer pumps and stand by requirements.		
5,14, 4. 2.1	Oil fuel pumps to be capable of being stopped remotely.		
5,14, 4. 3.1	Relief valves on pumps.		
5,14, 4. 4.1	Pump connections for overhauling purposes.		
5,14, 4. 5.1	Pipes conveying heated oil.		
5,14, 4. 5.2	Pipe flanges and jointing material impervious to 150°C.		
5,14, 4. 5.3	Short joining lengths of pipes to burners.		
5,14, 4. 5.4	Flexible hoses to be of approved type.		
5,14, 4. 5.5	For flexible hoses see Ch. 12.6.		
5,14, 4. 6.1	Low pressure pipes.		
5,14, 4. 6.2	Bilge pipes in way of double bottom tanks see Ch. 12. 13.7.9 and 7.10.		
5,14, 4. 7.1	Valves and cocks and their pipe connections.		
5,14, 4. 7.2	Control of valves and cocks in oil fuel installations.		
5,14, 4. 7.3	Oil fuel suction pipes from D.B. tanks.		
5,14, 4. 8.1	Deep tank valves and their control arrangements.		
5,14, 4. 8.2	Control of valves in engine and boiler spaces.		
5,14, 4. 8.3	Special consideration for small tanks.		
5,14, 4. 8.4	Oil fuel suction pipes to E.R. or B.R. from tanks above D.B.		
5,14, 4. 8.5	Filling pipes to deep oil tanks.		
5,14, 4. 9.2	Water drains to bunker and service tanks.		
5,14, 4. 9.3	Open drains to be fitted with S.C. cocks or valves.		
5,14, 4. 10.1	Relief valves on oil heaters.		
5,14, 4. 11.1	Filling station drainage and ventilation.		
5,14, 4. 11.2	Provision against overpressure and discharge to safe position.		
5,14, 4. 12.1	Passenger ship transfer arrangement.		
5,14, 4. 13.1	Alternative carriage of oil fuel/water ballast.		
5,14, 4. 13.2	Capacity of settling or service tanks.		

OIL FUEL SYSTEMS

SHEET No.:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 4 (contd.)		
5,14, 4. 13.3	Regulations of National Authorities—Pollution of sea by oil.		
5,14, 4. 14.1	Deep tanks for carriage of oil/water ballast dry cargo.		
5,14, 4. 14.2	Deep tank overflow arrangements.		
5,14, 4. 15.1	Separation of cargo oils from oil fuel.		
5,14, 4. 16.1	Fresh water piping.		
5,14, 4. 17.1	Separate oil fuel tanks.		
5,14, 4. 17.2	Plate thickness of rectangular steel tanks Table 14.4.1.		
5,14, 4. 17.3	Breadth of panel between supports Table 14.4.1.		
5,14, 4. 17.4	Panel stiffeners.		
5,14, 4. 17.5	Requirements for tank test.		
	SECTION 5		
5,14, 5. 1.1	Provision for expansion.		
5,14, 5. 1.2	Particulars required for expansion pieces.		
5,14, 5. 1.3	Installation requirements for expansion pieces Ch. 13.2.8.		
5,14, 5. 2.1	Drainage of steam pipes.		
5,14, 5. 2.2	Access arrangements to drain valves.		
5,14, 5. 3.1	Pipes in way of holds.		
5,14, 5. 3.2	Pipes led through shaft tunnels, duct keels, cargo holds.		
5,14, 5. 4.1	Reduced pressure lines.		
5,14, 5. 5.1	Steam for fire extinguishing in cargo holds.		
5,14, 5. 5.2	Details of proposed precautionary measures. For steam heating of oil fuel, cargo oil, lubricating oil see 5,14, 2.6.		
	SECTION 6		
5,14, 6. 1.1	Boiler feed water piping.		
5,14, 6. 2.1	Number of feed pumps required.		
5,14, 6. 2.2	Drive for feed pumps.		
5,14, 6. 2.3	Feed pumps in twin screw ships.		
5,14, 6. 2.4	Automatic regulators for independent feed pumps.		
5,14, 6. 3.2	Harbour feed pumps—second means of feed for boilers.		
5,14, 6. 3.2	Harbour feed pumps used as general service pump.		
5,14, 6. 3.3	Suction valves to hotwell, condenser, drain tank or filter.		
5,14, 6. 4.1	Number and arrangement of condensate pumps.		
5,14, 6. 5.1	Valves and cocks on feed and condensate pumps.		
5,14, 6. 6.1	Reserve feed water tanks.		

OIL FUEL SYSTEMS

SHEET No.:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 7		
5,14, 7. 1.1	Engine cooling water systems—main supply.		
5,14, 7. 1.2	Sea inlet scoop arrangements.		
5,14, 7. 2.1	Standby supply arrangements.		
5,14, 7. 2.2	Cooling water arrangements.		
5,14, 7. 3.1	Selection of standby pumps.		
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5,14, 8. 1.1	Lubricating oil pump standby arrangements.		
5,14, 8. 1.2	Capacity of standby pump.		
5,14, 8. 1.3	Provisions for separate lubricating oil systems.		
5,14, 8. 2.1	Control of pumps.		
5,14, 8. 3.1	Relief valves on pumps.		
5,14, 8. 4.1	Pressure alarms—audible and visual.		
5,14, 8. 5.1	Emergency supply of lubricating oil.		
5,14, 8. 5.2	Duration of emergency supply.		
5,14, 8. 5.3	Alternative supply arrangements.		
5,14, 8. 5.4	Automatic shutdown arrangements.		
5,14, 8. 6.1	Bearing lubrication and sump drainage.		
5,14, 8. 6.2	Bearing lubrication of electric generators and motors.		
5,14, 8. 7.1	Filters.		
5,14, 8. 7.2	Magnetic strainers and filters.		
5,14, 8. 8.1	Cleanliness of pipes and fittings.		
5,14, 8. 9.1	Outlet valves and cocks on tanks.		
5,14, 8. 9.2	Special consideration for small tanks.		
5,14, 8. 9.3	D.B. lubricating oil tank shut off requirements.		

OIL AND CHEMICAL TANKERS CARGO SYSTEMS

SHEET No.:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 1		
5,15, 1. 1.1	Requirements additional to those of Ch. 13.		
5,15, 1. 1.2	Requirements assume tanker type ship-machinery aft.		
5,15, 1. 1.3	Requirements applicable liquid F.P. $< 60°C$.		
5,15, 1. 1.4	Requirements for liquid F.P. $> 60°C$.		
5,15, 1. 1.5	Chemical cargoes as per table 15.1.1, 15.1.2, 15.1.3.		
5,15, 1. 1.6	Cargo Type A ships Table 15.1.1.		
5,15, 1. 1.7	Cargo Type B ships Table 15.1.2.		
5,15, 1. 1.8	Cargo Type C ships Table 15.1.3.		
5,15, 1. 2.1	Plans and particulars.		
5,15, 1. 3.1	Materials for cargo systems.		
5,15, 1. 3.2	Other piping systems in contact with cargo.		
5,15, 1. 4.1	Design pressure 1·03 N/mm^2.		
5,15, 1. 4.2	Piping to be seamless and as per Ch. 12.		
5,15, 1. 4.3	Joints in cargo piping outside cargo tanks.		
5,15, 1. 5.1	Dangerous spaces.		
5,15, 1. 5.2	Dangerous zones and electrical equipment.		
5,15, 1. 6.1	Cargo pump room—isolated drainage arrangements.		
5,15, 1. 6.2	Access to pump rooms in cargo area.		
5,15, 1. 6.3	Steam drain pipes—termination above bilges.		
5,15, 1. 7.1	Cargo pump room ventilation.		
5,15, 1. 7.2	Control of ventilation system and notice.		
5,15, 1. 7.3	Ventilation—number of air changes per hour.		
5,15, 1. 7.4	Number of changes per hour as per Tables 15.1.1 and 15.1.2.		
5,15, 1. 7.5	Number of changes based on gross volume of space.		
5,15, 1. 7.6	Arrangement of ventilation ducting.		
5,15, 1. 7.7	Prevention of incendive sparking.		
5,15, 1. 7.8	Renewable flame screens.		
5,15, 1. 7.9	Vent exits 3 m above deck.		
5,15, 1. 7.10	Type A or B ships discharge from vent exits.		
5,15, 1. 8.1	Slop tanks.		
5,15, 1. 8.2	Venting of slop tanks.		
5,15, 1. 8.3	Portable gas detectors.		
5,15, 1. 8.4	Slop tank pumping system.		
5,15, 1. 8.5	Ventilation of spaces surrounding slop tanks.		
5,15, 1. 8.6	Warning notices.		
5,15, 1. 8.7	Inert gas system for slop tanks.		
5,15, 1. 9.1	Steam connections to cargo tanks.		
5,15, 1. 9.2	Steam connections for Type A or B cargoes.		

OIL AND CHEMICAL TANKERS CARGO SYSTEMS

SHEET No.:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 2		
5,15, 2. 1.1	Bilge, ballast, oil fuel pumping arrangements at ends of ship.		
5,15, 2. 1.2	Bilge, ballast, oil fuel pipes not to pass through cargo tanks etc.		
5,15, 2. 1.3	Oil fuel bunkering and cargo systems to be separate.		
5,15, 2. 2.1	Cargo pump room drainage.		
5,15, 2. 2.2	Operation of bilge system—Type A or Type B tankers.		
5,15, 2. 3.1	Deep cofferdam drainage.		
5,15, 2. 3.2	Deep cofferdam water ballast arrangements.		
5,15, 2. 3.3	Drainage of dry cofferdams.		
5,15, 2. 3.4	Cofferdams—no connections to cargo tanks or cargo lines.		
5,15, 2. 4.1	Drainage of W.B. tanks/cofferdams forward of cargo tanks.		
5,15, 2. 5.1	Drainage of W.B. tanks/void spaces within range of cargo tanks.		
5,15, 2. 5.2	Connection of M/C space pumps to D.B./wing tanks within range of cargo tanks.		
5,15, 2. 6.1	Clean ballast piping in way of cargo tanks.		
5,15, 2. 6.2	Ballast and cargo oil pipes separate—emergency discharge.		
5,15, 2. 6.3	Forward W.B. tanks treated as dangerous spaces.		
5,15, 2. 7.1	Air and sounding pipes to deep cofferdams.		
5,15, 2. 7.2	Air and sounding pipes not to pass through cargo tanks.		
	SECTION 3		
5,15, 3. 1.1	Cargo handling system.		
5,15, 3. 1.2	Standby means of pumping cargo.		
5,15, 3. 1.3	Deep well/submerged pumps—alternative means for emptying tanks.		
5,15, 3. 1.4	Gas freeing of cargo tanks—ventilation of adjacent compartment.		
5,15, 3. 1.5	Two portable gas detection instruments.		
5,15, 3. 1.6	Location of cargo tank hatches and tank openings.		
5,15, 3. 2.1	Cargo oil pumps.		
5,15, 3. 2.2	Stopping cargo pumps from outside pump room.		
5,15, 3. 2.3	Pump discharge pressure gauges for type A/B tankers.		
5,15, 3. 2.4	Pump relief valves—provision against over pressure.		
5,15, 3. 2.5	Gas tight glands at pump room bulkhead/deck.		

OIL AND CHEMICAL TANKERS CARGO SYSTEMS

SHEET No.:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 3 (contd.)		
5,15, 3. 2.6	Location of cargo pumps for certain Type A cargoes.		
5,15, 3. 2.7	Contamination of cargo liquid by hydraulic motor liquid.		
5,15, 3. 3.1	Cargo piping not to pass through tanks outside cargo tank area.		
5,15, 3. 3.2	Drainage of cargo pumps and pipes—drain tank arrangements.		
5,15, 3. 3.3	Expansion joints/bends in cargo pipe lines.		
5,15, 3. 3.4	Steel bellows for Type A/B cargo piping.		
5,15, 3. 4.1	Terminal pipes and fittings to be of steel.		
5,15, 3. 4.2	Manual shut off valve for shore loading/discharge pipes.		
5,15, 3. 5.1	Bow/stern loading/discharge arrangement.		
5,15, 3. 5.2	Dangerous space within 3 m of discharge manifold.		
5,15, 3. 5.3	Arrangements acceptable Type C—special consideration Type A/B.		
5,15, 3. 6.1	Cargo segregation.		
5,15, 3. 6.2	Cargo piping not to be led through incompatible tank.		
5,15, 3. 7.1	Direct loading pipes to be as low as practicable in tank.		
5,15, 3. 7.2	Deck control of valves to tanks below weather deck.		
5,15, 3. 8.1	Remote control valves to be arranged for manual operation.		
5,15, 3. 8.2	Two suctions in tank for valves/actuators inside tank.		
5,15, 3. 8.3	Actuators to prevent inadvertent opening. Indicators required.		
5,15, 3. 8.4	Materials of piping and actuators to be suitable for cargo.		
5,15, 3. 8.5	Compressed air not to be used for actuators inside tanks.		
5,15, 3. 8.6	F.P. of hydraulic oil to be 60°C or above and compatible.		
5,15, 3. 8.7	Cargo liquid not to be contaminated by operating medium.		
5,15, 3. 8.8	Location, type, venting and alarms for medium supply tank.		
5,15, 3. 8.9	Emergency control of non-manual valves.		
5,15, 3. 9.1	Electrical circuits in dangerous spaces to be safe.		
5,15, 3. 9.2	Arrangement of controls and instruments.		
5,15, 3. 9.3	Communication between control stations bridge, deck, M/C space.		
5,15, 3. 9.4	Cargo controls/instruments to be separate from main aux M/C controls.		

CHAPTER 15 SHIP PIPING SYSTEMS

OIL AND CHEMICAL TANKERS CARGO SYSTEMS

SHEET No.:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 4		
5,15, 4. 1.1	Cargo tank—venting to limit pressure/vacuum in tanks.		
5,15, 4. 1.2	Liquid head to be less than test head, controls to be provided.		
5,15, 4. 1.3	Cargo tank venting arrangements (a) P/V release (b) venting.		
5,15, 4. 2.1	P.V. and venting system may be separate.		
5,15, 4. 2.2	Venting systems to permit free flow or discharge 30 m/sec.		
5,15, 4. 2.3	Standpipes to be at top of tank, means of isolation where applicable.		
5,15, 4. 2.4	Means to prevent excessive pressure/vacuum.		
5,15, 4. 2.5	Set pressures for P.V. valves.		
5,15, 4. 2.6	Arrangements for P.V. and by-pass valves.		
5,15, 4. 2.7	Area of venting system for cargo loading. G.E. factor 1·25.		
5,15, 4. 2.8	Drainage arrangements for vapour lines.		
5,15, 4. 3.1	Arrangement of vapour inlets/outlets. Material of wire gauzes.		
5,15, 4. 3.2	Vent and P.V. outlets to discharge vertically upwards.		
5,15, 4. 4.1	Vapour return connections to shore. Blank flanges, shut off valves.		
5,15, 4. 5.1	Height and location of cargo tank outlets.		
5,15, 4. 5.2	Height of vapour outlets above deck. Tables 15.1.1, 15.1.2 cargoes.		
5,15, 4. 5.3	Height of P.V. outlets above deck for Type A/B tankers.		
5,15, 4. 5.4	High velocity vents 30 m/sec. Height of outlets.		
	SECTION 5		
5,15, 5. 1.1	Means for ascertaining liquid level in tank.		
5,15, 5. 2.1	Restricted sounding device.		
5,15, 5. 2.2	Separate ullage openings as reserve means for sounding.		
5,15, 5. 2.3	Escape of vapour to atmosphere not to be fitted in enclosed spaces.		
5,15, 5. 3.1	Closed sounding devices of approved type.		
5,15, 5. 3.2	Indirect sounding methods to be specially considered.		
5,15, 5. 4.1	High level audible and visual alarm.		
5,15, 5. 5.1	Overflow control—high level alarm—avoidance of accidental spillage.		

CHAPTER 15 SHIP PIPING SYSTEMS

OIL AND CHEMICAL TANKERS CARGO SYSTEMS

SHEET No.:

PARA No.:		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 6		
5,15, 6. 1.1	Cargo heating system to comply with 6.2 to 6.5.		
5,15, 6. 2.1	Blanking arrangements for tank heating coils.		
5,15, 6. 3.1	Heating medium to be compatible with cargo.		
5,15, 6. 3.2	F.P. $>$ 60°C for combustible heating liquid.		
5,15, 6. 3.3	Temperature of heating medium 220°C.		
5,15, 6. 4.1	Arrangement of heating circuits.		
5,15, 6. 4.2	Shut off valves on heating coils.		
5,15, 6. 4.3	Test cocks on heating coils Type A/B tankers.		
5,15, 6. 4.4	Type A/B tankers—provision for sampling heating return lines.		
5,15, 6. 4.5	Location and arrangement of observation tank.		
5,15, 6. 4.6	Type A/B toxic cargoes—observation tank arrangements.		
5,15, 6. 4.7	Contamination of cargo liquid by thermal oil.		
5,15, 6. 4.8	Higher pressure/drainage/blanking of heating circuit.		
5,15, 6. 5.1	Cargo temperature measurement—alarm system.		
	SECTION 7		
5,15, 7. 1.1	Inert gas system where F.P. cargo oil $<$ 60°C.		
5,15, 7. 1.2	Ships eligible for "IGS" notation.		
5,15, 7. 2.1	Inert gas supply.		
5,15, 7. 2.2	Quantity of inert gas continuously available.		
5,15, 7. 2.3	Capacity of inert gas system at max. unloading rate.		
5,15, 7. 2.4	Oxygen content of inert gas.		
5,15, 7. 2.5	Shut off valves at boiler uptakes. Operation of soot blowers.		
5,15, 7. 2.6	Clearing of valves adjacent to boiler uptake.		
5,15, 7. 3.1	Gas scrubber and filters to be fitted.		
5,15, 7. 4.1	Two gas blowers (minimum) to be provided.		
5,15, 7. 4.2	Gas pressures on tanks 0·24 kgf/cm^2.		
5,15, 7. 4.3	Shut off valves on blower suction/discharge.		
5,15, 7. 4.4	Arrangements for stabilizing plant before cargo discharge.		
5,15, 7. 4.5	Provision for fresh air purging—air inlets to be blanked.		
5,15, 7. 5.1	Cooling water supply arrangements.		
5,15, 7. 6.1	Bulkhead gas control valve arrangements.		
5,15, 7. 6.2	Two N.R. devices—one to be a water seal.		

OIL AND CHEMICAL TANKERS CARGO SYSTEMS

SHEET No.:

PARA No.		COMPLIED WITH	NOT COMPLIED WITH
	SECTION 7 (contd.)		
5,15, 7. 6.3	Water seal to remain efficient under all conditions.		
5,15, 7. 6.4	Liquid filled P.V. breaking device or equivalent.		
5,15, 7. 6.5	Tanks to be capable of being isolated from gas line.		
5,15, 7. 6.6	Fitting of connections between inert gas main and cargo pipe system.		
5,15, 7. 6.7	Gas pressure 0.2 kgf/cm² to be maintained in tanks.		
5,15, 7. 7.1	Vapour escape/vacuum relief through approved system.		
5,15, 7. 7.2	Fitting of purge pipes. Location of inlets and outlets.		
5,15, 7. 7.3	Purge pipes to permit gas/air velocity 20 m/sec.		
5,15, 7. 7.4	Purge pipes to be remote from gas/air entry—blanking arrangements.		
5,15, 7. 8.1	Automatic shut down devices and/or alarms.		
5,15, 7. 9.1	Instruments for monitoring inert gas supply to tanks.		
5,15, 7. 10.1	Installation and tests to Surveyor's satisfaction. Table 15.7.1 items requiring alarms.		
	SECTION 8		
5,15, 8. 1.1	Chemical cargo tanks and spaces requiring inert gas.		
5,15, 8. 1.2	Arrangements as per Section 7 where applicable.		
5,15, 8. 1.3	Capacity of inert gas system for adjacent spaces and/or padding.		
5,15, 8. 1.4	Inert gas to be suitable for cargoes carried.		
5,15, 8. 1.5	Means to be provided for indicating pressure in tank/spaces.		
5,15, 8. 1.6	Monitoring ullage and other spaces containing inert gas.		
5,15, 8. 2.1	Inert gas piping arrangements as per 8.5.5 to 8.2.6.		
5,15, 8. 2.2	Piping system on board and shore connections.		
5,15, 8. 2.3	Arrangements to prevent back flow of cargo vapour.		
5,15, 8. 2.4	Inerted spaces—positive pressure—isolation —over pressure.		
5,15, 8. 2.5	Inert gas piping system to tanks to be separate.		
5,15, 8. 2.6	Purging/gas freeing connections between IGS and cargo system.		

WRITTEN CONTRIBUTIONS

From Mr. A. K. Buckle:

I will confine my comments to section 9. Some of our colleagues may not be aware of the existence of the recently published IMCO Code on Dynamically Supported Craft. This Code defines such craft as being those where:—

(a) the weight, or a significant part thereof, is balanced in one mode of operation by other than hydrostatic forces

(b) the craft is able to operate at speeds such that $\frac{V}{gL} = 0{\cdot}9$ where V = speed, g $\simeq$ acceleration due to gravity and L = waterline length. All in consistent units.

This definition was designed to include certain planing craft as well as hovercraft and hydrofoils.

The Code differs from the Rules, as used up to now, in a number of ways. For example, operating areas have an upper limit of 100 nautical miles from a place of refuge, compared with the Rule limit quoted in 9.3 of 110 kilometres, also the capacities and numbers of bilge pumps tend to be less severe than the Rule requirements. But, and this is a very important "but", there is very much stricter control of operation procedures, communications, inspections etc., than for ordinary ships. The aim is to obtain *equal* safety to ships, not to give relaxations on safety. It follows that if the Code is used then it is all to be used. The selection of some "Rule" items and some "Code" items is not permitted by the Authorities.

From Mr. B. Wilson:

Every conceivable compliment was rendered to Mr. Crawford during the verbal discussion on his Paper on the evening of its presentation and I would like to endorse wholeheartedly each one, even though I would not presume to understand the entire text, since its scope is (in most aspects) outside my experience as a Ship Surveyor involved in hull plan approval.

There are however, several questions I would like to ask, as well as some observations which I hope may be worthwhile. The references at the side relate to the paragraph numbers.

2. For the sake of clarity could the Author include the usual symbols for the various fittings you have listed.

3.2 The last paragraph is not clear to me, in particular, how one defines the "light load waterline".

Can you please explain what "Self closing cocks having parallel plugs" are?

4.3.17 I would like to suggest that Part 4, Chapter 1, 9 of the 1978 rules, could be applied to determine small tank scantlings.

8.2 It would be of interest to learn the necessary requirements for oil fuel when carried below cargo oil tanks in O.B.O. ships, although this practice would seem undesirable.

What are your ideas on the length of duct keels from the point of view of access arrangements and the need, or otherwise, of intermediate accesses between those at the ends? Pipe tunnels can present the ship plan approval Surveyor with problems with regard to maintaining transverse strength in the double bottom, particularly when these occur near the sides of the ship.

I understand it is the policy of some Owners to store spare lengths of each pipe size in pipe passages for repair purposes until required. This obviates the need for either expensive cutting of the inner bottom or bottom shell or the need for the taking in of short lengths of pipe.

It has never been clear to me how the space contained between the top of bulkhead stools, the corrugations and the shedder plates can be "gas freed" (and I am sure that other small pockets can exist). Perhaps you could advise on this matter?

8.3 It may be of interest to mention that unlike the majority of ship types, container ships are more sensitive to openings being cut in their uppermost continuous deck, since the top flange of their hull girders consists of narrow longitudinal strips kept apart by narrow cross deck elements at the ends of very large hatchway openings. It is worth noting, therefore, that whilst an opening for an air pipe or the like, can be cut into the deck of say, a bulk carrier with perhaps negligible effect, any proposed openings in the deck, particularly those near the engine room front in a container ship, when not envisaged at the approval stage of the deck plating, can present serious problems to both the Surveyor at the building (or repair) yard and to the ship plan approval Surveyor.

Again in recent container ships, it is usual for the holds to be of such a length as to accommodate two forty feet containers length-wise with a half hold box girder/pillaring arrangement fitted between. This arrangement usually incorporates a box girder at inner bottom level transversing the breadth of ship, being two or three frame spaces wide and usually being a height of one container high. In the event of this box being made intact (which I believe is quite common) presumably bilge wells will be required to both the forward and after space of the "common hold space".

From Mr. J. R. G. Smith:

As the Author is aware, in addition to normal Classification work on Chemical Tankers, the Society is frequently involved in plan appraisal work with a view to compliance with the IMCO Code for the Construction and Equipment of Ships Carrying Dangerous Chemicals in Bulk. In carrying out the co-ordination of this work in I.C.D. one of the most frequently heard queries from Owners is "What is a restricted gauging device?" The Author refers to sounding devices on Chemical Tankers in paragraph 5.2.4 of his very comprehensive Paper, but could he please give us some examples of acceptable restricted gauging devices designed to ensure that no dangerous escape of tank contents (liquid or spray) can take place in opening the device?

Additionally, it would appear from paragraph 5.2.4 that all chemical tankers must have either restricted or closed gauging devices. Paragraph 5.2.1 however, states that the pumping requirements for Type "C" Chemical Tankers are the same as for Oil Tankers. As open gauging is permitted on oil tankers, could the Author please confirm that open gauging is also permissible for Type "C" Chemical Tankers?

From Mr. M. R. Skillman:

I would wish to query the statement in 11.1. "When the the machinery and piping systems of offshore units are essential to the safety of the unit they should comply with the Rules for Steel Ships".

Presumably, Chapter 1 of the IACS draft "Unified Requirements for Mobile Offshore Drilling Units and other Similar Units", represents the present position of this and other member Societies of IACS on requirements for machinery pumping and piping of mobile units. Does the Author have any views on Chapter 1?

In my view, Chapter 1 is not satisfactory in that its requirements do not go far enough to fully support and complement the requirements of the IACS draft rules which deal with intact and damage stability.

From Mr. R. Hales:

I congratulate Mr. Crawford for compiling a wealth of information contained in his Paper which will, I am sure, stand as a guide for many years to come.

However, I would like his comments on one point. He mentions the provision of heating to avoid hypothermia by the effects of cold in diving compression chambers but he does not say anything about too much heat.

I would suggest, in order to avoid confusion, the use of words other than Hypothermia or Hyperthermia since these are similar sounding but opposite in meaning. In the case of helium-oxygen atmospheres under pressure the temperature limit between the two conditions is only 2°C (4°F). I wonder therefore whether he omitted that cooling may also be necessary, especially in hotter climates.

From Mr. K. D. Boothman:

The Author's Paper represents a timely replacement to Mr. Clayton's classic effort in the 1959/60 Session.

It is appreciated that Mr. Crawford's Paper has been written with Classification requirements in mind, however, it is considered that reference to the effect of damage stability requirements on the design of piping arrangements would be most desirable. Many types of ship are regulated by IMCO Conventions or Codes; at present damage stability requirements affect the following types of ship:—

TYPE "A"
TYPE "B-60" } 1966 Load Line Convention.
TYPE "B-100"

CHEMICAL TANKERS — Chemical Code
GAS CARRIERS — Gas Code
PASSENGER SHIPS — S.O.L.A.S.

In these ships, the possibility of progressive flooding through damaged pipes and valves within the transverse and vertical limits of damage or undamaged pipes and valves anywhere must be taken into account.

Progressive flooding is only acceptable when damage stability calculations show that the ship can survive such flooding and satisfy the Convention or Code requirements.

The Author's comments on the above would be appreciated.

From Mr. M . A. Fingalsen:

Under section 3.9 of the Paper, you draw attention to the possibility of damaging the tank by over-pressure if the air or overflow pipe has become blocked.

I should like to mention also a number of cases of damage to the cargo tanks of oil tankers fitted with an inert gas system. The vessels in question had shut-off valves in the inert gas line fitted at the hatch in association with an individual pressure vacuum relief valve system similar to that shown in Fig. 39 (p. 34) at the upper left-hand side of the sketch. Nevertheless, whilst ballasting with the inert gas system in operation, damage was caused due to overpressure where the inert gas isolating valve was shut. This varied from damage to the O.T. transverse bulkhead only, to cases where the deck also was set up and fractured.

One possibility, of course, is mal-operation such as failing to open the lid shown on Fig. 28 (p. 27), or blockage of the gauzes. In some cases, this has been difficult to prove in practice due to the reluctance of the ship's personnel to confirm suspected mal-operation. The other possibility that remains is the adequacy of the design venting arrangements to cope with the maximum pumping rates which could be applied.

As you say in the Paper, the Rules require that means are to be provided to prevent the tank from being subjected to excessive pressure. However, I understand that the sizing of these arrangements in relation to the pumping capacity is the responsibility of the Builder. If this is so, perhaps you could comment on the desirability of the Society checking this aspect as part of the plan approval procedure by means of calculations or test results submitted by the Builders?

AUTHOR'S REPLY

Initially I would take this opportunity of thanking those colleagues who have contributed to the discussion.

To Mr. E. Howey:

To your first point I would make the following comments. The Society's Rules, whilst not requiring shipside valves to be provided with remote control, do not exclude such arrangements, provided arrangements are made for manual operations in the event of loss of operating power in the remote control sysems. Indeed, such arrangements have been submitted for approval and subsequently accepted subject to a hand power unit being permanently installed at the valve actuator.

If such a requirement was to be considered for inclusion in the Rules, quoting a "large valve" could lead to some confusion, since different people have various ideas as to what is a large valve. Such a requirement would have to be restricted to specific systems. It is known, for example, that one National Authority has such a requirement in the case of U.M.S notation in relation to main and auxiliary cooling water systems, sea inlets and discharges.

With regard to your second point, it is not seen that any advantage can be gained by adding additional valves in an already congested pump room. If the reason for the additional valve is a precaution against flooding, it may be more appropriate to provide increased thickness of the sea connection and piping.

It is concluded that Mr. Howey in his third point is referring to cases where the closed ullage does not extend to the lower part of the tank. In such cases provision could be made for sounding the tank via a small diameter sounding pipe which, when opened, could be considered on the basis of a restricted sounding. It will be appreciated, however, that before such a sounding pipe could be used it would be necessary to depressurise the tank.

To Mr. B. W. Oxford:

With regard to isolation of cargo tanks and provisions for preventing over-pressure, it is agreed a pressure/vacuum (P/V) valve, unless sized to cope with full loading conditions, would not protect the tank in the case of overfilling during loading. The main purpose of the P/V valve is to cater for the minor fluctuations of pressure during the voyage, always presuming of course that the valves are not seized due to liberal coats of paint. Tanker loading is a specialised operation and subject to adequate supervision to prevent overfilling. The P/V valves could possibly prevent serious damage to the structure of the tank in the event of inadvertent closing of the isolating valve.

I am not in favour of the use of portable fittings as they are open to abuse, In this respect it may be well to add that Classification is concerned with fixed installations on board ships and does not generally concern itself with portable equipment. It will be appreciated that storage, maintenance and connections of portable units cannot be supervised by the Society and are the Owner's responsibility.

Mr. Oxford's comments regarding floodable holds are concurred with, as indicated in Paragraph 3.10 of the Paper.

To Mr. R. Gardiner:

Tank Suction, Filling and Air Pipes

It is agreed that cases have arisen whereby air pipes from void spaces and cofferdams on pontoons and barges have not been insisted upon. However, it must be appreciated this arrangement is contrary to the Society's Rules which require provision to be made for ventilating such compartments. Acceptance in such instances *is a concession* based on the particular service for which the unit is intended, each case being decided on its own merits.

Flooding of Holds

My main point here is to draw attention to the necessity of ensuring adequate ventilation to these compartments. In the case of deep tanks, on lower-hold flooding arrangements, provision of ventilation will be complied with in the normal manner as required by the Rules. However, in the case of a "hold" being flooded, ventilation may be supplied via the hold ventilation "jalouses". Should these jalouses be closed, e.g. with canvas hoods, damage to the ship structure could occur during de-ballasting.

Remote Control Valves

In connection with ship-side valves please refer to my reply to Mr. Howey's contribution.

Starting from Cold "First Starting"

It is agreed that, whilst in general, starting systems relying on a "Film Strip" are not looked upon with favour, the "Hansa" starting arrangement has been accepted on the conditions outlined in the Instructions to Surveyors, Amendment 10. Part 2b., 1965 dated 10/6/65.

Location of Cargo Tank Open Vents

Your comments are concurred with. Indeed, if and when the IMCO Protocol to 1973 Pollutions act is ratified, tankers exceeding 20,000 DWT will be required to be provided with inert gas systems. Such systems would, of course, be provided with "closed" vent systems. However, even closed systems will terminate in open vent pipes. Fig. 27 indicates the locations of such open vent pipes as accepted by the Rules.

It may be as well to add at this point that in all cases the open vents/pressure-vacuum valves, where fitted, are required to be fitted with efficient renewable wire gauzes on safety heads of approved type.

Container Ships

Your comments only serve to confirm my own views regarding such arrangements. However, the facts are, as confirmed by yourself, that such arrangements have been accepted subject to "restricted" Classification.

To Mr. R. B. Siggers:

Mr. Siggers' remarks regarding the painting over of air closing devices is surely equally applicable to all types, including ball type closing devices. Paint in or on the over enthusiastic hand of the operator being no respector of individual items of equipment. However, the Society's Rules are based on the understanding that the ship will be properly handled and surely this includes maintaining these items in an operational condition. Maintenance is the responsibility of the Owner/Ship's complement.

As requested by Mr. Siggers, a sketch of an automatic non-return closing arrangement incorporating ball float valves is shown see Fig. 1. This sketch shows two types, one incorporating double ball float valves and the other a single ball float valve. The latter indicates an arrangement whereby the vent outlet is connected to the ship's side as may be found on car-ferry installations where the air pipe would otherwise terminate in the enclosed car-deck. The Surveyors' attention is drawn to Circular No. 2270 "Closing Appliances for Air Pipes", when Ball floats are made of polythene etc.

Valves Located within Ballast Tanks

It is agreed the use of single valves located within the ballast tanks have been accepted subject to provision for operating the valves in the event of failure of the operating remote control systems. This is acknowledged in paragraph 4.2.1 of my Paper.

Mr. Siggers asks whether the Society should bow to the inevitable and delete the requirements on accessibility. Personally, I do not accept the reference to "the inevitable". The present acceptance of the single valve within the tank has been restricted to ballast systems only, and would appear to be based on loss of operating power to the valve actuator. If the actuator is located above deck it would be a comparatively easy matter to restore operating power by means of a portable hand unit via suitable connections. Should, however, the actuator be located within the tank or a loss of operating power be due to failure of the power supply within the tank, this could render the whole system inoperable. In the case of deep tanks or, for instance, the cargo tanks on tankers this could be overcome by means of a portable pump, the tank being pumped out via a flexible suction hose, (as in the case of discharging edible oil tanks when a fixed pumping system is not provided). This provision in effect endorses the acceptance factor.

This would not be possible in the case of double bottom tanks whereby access is normally via a manhole in the tank top, unless of course the hold was empty. Whilst such an arrangement could be considered in respect of systems *NOT* considered essential to the safety of the ship, it is my opinion that for essential services the requirement regard-

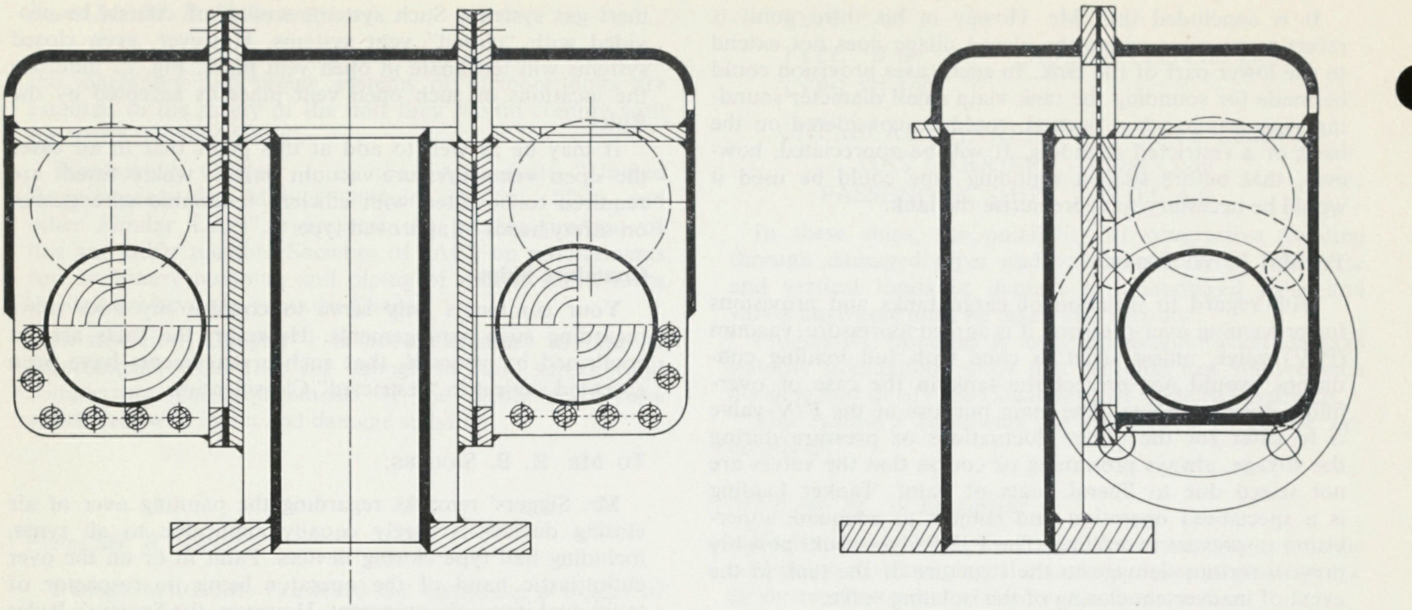

FIG. 1

ing accessibility (or equivalent requirements) must be retained.

Regarding Dropping Valves for Topside Tanks

Dropping valves have been used as an acceptable means of draining topside tanks for a number of years on the basis that the bottom of the tank is normally above the waterline. Cases have been accepted where the bottom of the tank is on or marginally below the load waterline on the basis that:—

(a) These tanks are normally empty when the ship is in the loaded condition.

(b) When used for ballasting purposes in the light load condition, the tank drainage outlets are above the waterline.

(c) Should the occasion occur where these tanks, or specified tanks are used for the carriage of water ballast in the loaded conditions, drainage of the tank would result in the dropping valve rising above the waterline due to the reduced draught.

TO MR. R. P. HOLBROOK:

It is agreed that the Rules for "Fuel Gas Burning" include requirements for use in conjunction with main oil engines. The requirements are essentially the same, any difference being restricted to the connections in way of the boiler or main oil engine.

With regard to the operating pressure in the supply to the units, this is adequately covered in the Rules for Ships for Liquefied Gas, Chapter XVI, paragraph LR. 16.1.01. It is not thought that any significant pressure drop would be experienced in the length of piping from the machinery space bulkhead to the boiler or main oil engine, say a maximum of 1lb/in² pressure drop in a pipe length of say 50 m (150 feet). Any pressure drop would of course have to be taken into account by the designer for the particular application.

As a point of interest, to my knowledge the use of fuel gas (Methane) in conjunction with main propelling units has, to date, been restricted to use as boiler fuel.

When the Rules for Ships for Liquefied Gases, Chapter XVI "Use of Cargo as Fuel" were formulated, only L.N.G. (Liquefied Natural Gas-Methane) and L.P.G. (Liquefied Petroleum Gas-Propane/Butane) were considered for use as fuel for main propulsion units. The heavier than air gases, L.P.G./Propane/Butane were not considered suitable having regard to possible dangerous conditions that could arise in the event of leakage. Any gas leakage, by virtue of being heavier than air, would naturally fall to the lower part of the machinery spaces and would be extremely difficult to dispel by ventilation, more so, having regard to the congested area of the lower part of the machinery space. In view of the above, L.P.G. was not considered acceptable for use as fuel in machinery spaces.

Methane, on the other hand, having a specific gravity lighter than air (0·5 approx.) would, in the event of leakage, tend to rise and could be more readily dispersed before an explosive condition could arise. Consequently, use of L.N.G. (Methane) as fuel was considered acceptable subject to the conditions as outlined in the Rules for Liquefied Gas Ships, Chapter XVI.

I think your comments regarding the use of gases having a specific gravity not exceeding 0·9 is based on the fuel gases in conjunction with offshore installations, e.g. offshore production facilities, and storage tankers. Fuel gas, usually bled from the first or second stage separator units on production facilities, is extensively used in conjunction with gas turbine power units driving main generators, crude oil pumps and gas compressors. The gases vary in specific gravity from between 0·5 to 0·85, in all cases being lighter than air, and have been accepted on the basis of the Rules for fuel gas burning as applicable, as indicated in Chapter 11.3 (VI) and 11.4.1 of the Paper. In this context I see no objection to the use of fuel gas having a specific gravity, say, not exceeding 0·9 being used.

At this stage it may be well to point out that gases having specific gravity greater than 0·9 would not be considered acceptable for use in any enclosed areas.

L.N.G. Disposal in Port

The reason for utilising a special boiler in conjunction with a dump condenser is simply that:—

(a) It may be that the National Authority may not allow use of fuel gas burning for the main boilers in port.

(b) The main boiler may not have the capacity to utilise the total "boil off" during loading or unloading conditions in port.

My own thoughts are that an incinerator unit incorporating adequate cooling of the exhaust leaving the incinerator would appear most suitable, irrespective of type of main propulsion machinery.

Crude Oil Burning (see Fig. 41)

Dealing with each of your points in turn:—

1. This could be difficult due to changing trim of the ship, in which case no objection is seen to provision being made for draining at each end of the casing (fore and aft).

2. Agreed, but no objection is seen to the tray being incorporated within the ducting.

3. Yes, and this is shown in the sketch.

4.1 It is agreed that certain National Authoritites may prohibit the use of atomising steam in connection with distillate fuels. I understand this is in consequence of an explosion caused by auto-ignition of diesel fuel by high temperature atomising steam. It will, however, be appreciated that this is a National Authority regulation and is outside Classification requirements. In such cases it is always prudent to draw the Shipbuilders' attention to this point.

4.2 It is agreed that no steam or air piping is shown on the sketch, since the sketch was intended to indicate the minimum requirements in relation to the crude oil piping in way of the machinery space.

It is concluded the reference to steam or air purging refers to the burners. Steam/air purging systems may or may not be complicated. The main precaution is to ensure the fuel cannot enter the steam or air systems. It will be appreciated that apart from the purging of the boiler combustion space, the purging sequence does not have to be automatic.

Chapter 8 of the I.A.C.S Regulation 100 requires the remote control valves to be interlocked with the hood exhaust fan. This is indicated in Fig. 41, Note B.

The interlocking of the pump room fans and the crude oil fuel units is required in order to ensure adequate ventilation of the pump room whilst the crude oil unit pumps are operating. This requirement is additional to the I.A.C.S. regulations and has been applied where proposals for crude oil burning systems have been submitted for approval on ships classed with the Society.

Regarding the location of diesel and gas turbine units I would draw your attention to the Rules for the Construction and Classification of Ships which are applicable, in particular Part 5 Chapter 15,1.5.1 which indicates that oil engines are not to be located within prescribed areas (hazardous areas).

In the section under the heading Fixed Drilling Production Platforms I have indicated those areas which have been the subject of various discussions during the examination of plans in relation to Offshore Services, and to explain the basis on which the requirements are applied.

I would add that the requirements indicated under this section have been submitted for possible inclusion of the new Rules for Offshore Installations now under consideration.

Regarding Mr. Holbrook's comments on spark arresters; provision of a spark arrester, as generally termed, could possibly induce a back pressure and reduce the efficiency of the turbines, but, having regard to the turbine construction, have not been insisted upon. There is, however, always a possibility of hot particles of carbon being ejected from the exhaust and means should be provided to prevent this. This could take the form of internal directional baffle plates within the exhaust duct which would prevent the emission of these particles.

Overspeeding

I do not necessarily agree that blade efficiency will prevent overspeeding in itself. Indeed, attention has been drawn to the danger of overspeeding due to the ingestion of hydrocarbon vapours and possible surge at the compressor which could lead to an explosion within the air intake. It was considered that ingestion of hydro-carbon gas up to 10% L.E.L could be accommodated without unacceptable overspeed but ingestion of gas above the 10% L.E.L could lead to the conditions indicated above.

The main reason that provision against overspeeding (in the event of gas ingestion) in the case of gas turbines was not insisted upon, was based on the premise that prevention was better than the cure particularly when one considers the size of some air intakes on these units. The prevention is in the form of extending the air intake as far as practicable from any possible source of hazard.

Location of Gas Turbines

I would say that gas turbines along with other "fixed" appliances and internal combustion engines should be located within safe compartments. The dangers applicable in the case of the gas turbines are the low flash point fuel gas and the inherent high temperatures of these units. No objection is seen to the housing of a gas turbine unit within an area designated hazardous subject to the housing/enclosure being adequately ventilated from a safe area. Similarly, the combustion air and exhaust must also be led from and to safe locations.

Paragraph 11.4.2

Unfortunately, a sub-title has been omitted (11.4.3. "HAZARD OF HYDROGEN SULPHIDE"). Further, the paragraph does appear to be contained under the heading of Oil and Gas Fixed Boilers.

To Mr. C. Campbell:

Section 11.2 Fixed Platform

Where the unit is submitted for "Classification", all major machinery items and pressure vessels must be constructed under survey.

Insofar as the items of machinery are essential to the safety of the unit, then the same items are to be constructed under the usual conditions of survey and testing.

In the event that the main generating machinery consisted of two (2) main generating units it would be normal procedure to require the power units to be of an approved type and constructed under the normal classification requirements. Where the main power source consisted of three (3) or more power units, construction under the Society's survey would not be insisted upon, provided the units were constructed in accordance with a recognised National/International Standard. Suitable documentary evidence of construction and testing would be required to be submitted. Final acceptance is based on the unit being installed and tested in situ to the Surveyor's satifaction.

I can assure you that insofar as such units are submitted for Classification to MDAPAD, platform safety is no less important than ship safety.

Mr. Campbell must, however, differentiate between platforms submitted for Classification and those submitted for "certification" in accordance with National Authority requirements. In this respect, in accordance with the Department of Energy's Statutory Instrument No. 289 and subsequent Guidance Notes, those items required to be built under the Society' survey for Classification purposes, could

be accepted for Certification purposes based on construction and testing in accordance with a recognised National/International Standard.

Section 11.3 Gas and Oil Production Systems—Materials and Inspection

Materials for valves, pipes and fittings are considered in conjunction with the services intended and these are normally dealt with when the relevant specifications are submitted. The pipe thicknesses are checked in accordance with the specification design criteria. Similarly, types of valves and fittings are checked for suitability in relation to the service intended. Comments are made, as applicable, in the event of any of these items being considered unsuitable.

Regarding inspection standards, MDAPAD would consider that the inspection standards should be at least comparable with those for marine application. However, this particular responsibility lies with the L.R.I.S. which is responsible for the inspection of these items. In this respect, it is understood that in the case of H.P. fittings 100% inspection at the manufacturer's works is normally applied. In the case of L.P. domestic systems a 10% spot check is applicable and a special examination is applied to fittings for use in sour gas systems.

Valves—Fire Safe

In order to be accepted by the Society as "fire safe", for use in hydro-carbon or essential services, it will be necessary for the valve, if incorporating non-metallic seals, to be subject to a fire test as outlined in the BS 5146. The test is to be carried out by a Nationally recognised testing authority, if not witnessed by the Society's Surveyors, with satisfactory results. Acceptance of a specific design of valve is normally dealt with on the basis of 2 × the diameter of test valve. For example, assuming the size of a test valve was 10″, then on proof of satisfactory testing this design of valve would be accepted from 5″ (10/2) to 20″ (10 × 2). Any modifications to the design of the valve would, of course, render the acceptance void and the acceptance would then be withdrawn.

Interlocking Arrangements for Relief Devices

The Society is responsible for ensuring that an acceptable intelocking arrangement is provided. It is considered the platform operator's responsibility to ensure that proper use and maintenance is applied.

Approval of Pressure Systems' Line Diagrams

Subject to all relevant information being submitted in relation to materials, design, standards, safety, pressure relief systems indicated etc., it is felt that the present arrangements are adequate. The main problem here, of course, is that these details are not always submitted until after the work has been started, which results in various degrees of objections when modifications are required.

To Mr. R. J. Hook:

Regarding the source of the formulae for bilge main and branch sizes, the Society's requirements for bilge pipe sizes have been in use and remained relatively unchanged for a period of over 50 years. These empirical formulae bear a relationship to the wetted surface of the ship, or compartment, and first appeared in the 1922–23 edition of the Rules. At the same time, the requirement for a minimum water speed through the main bilge line, 400 ft/min. (122 m/min.) was introduced. These two standard parameters, pipe size and water speed, thus established the minimum pumping capacity in tons/hr. (m^3/hr) for each bilge pump. It would appear that the figure of 400 ft/min. (122 m/min.) was the average water speed which could be anticipated when using steam reciprocating pumps. Reference books on pump design at that time indicate that water speeds in piping associated with centrifugal pumps lag between 300 ft/min. and 500 ft./min. From this background we can surmise that this was the reason for the Society including in the Rules, the requirement that the bilge pumps should be capable of giving a speed of water through the Rule size of main bilge line of not less than 400 ft/min. (122 m/min.).

It is agreed that a publication comprised of the various items of equipment, such as ball valves, butterfly valves, expansion type couplings, etc., accepted by the Society for use in the various systems and service conditions, would prove of considerable value. However, I am sure Mr. Hook will be the first to appreciate that the documentation of the vast amount of equipment is outside the scope of a Technical Staff Association Paper.

The reference to properly attached end fittings for use in conjunction with flexible pipe lengths requires the end attachment to have a positive lock or "bite" into the pipe material when secured by swaging or crimping to the manufacturers' instructions. Typical attachments are shown in Fig. 2.

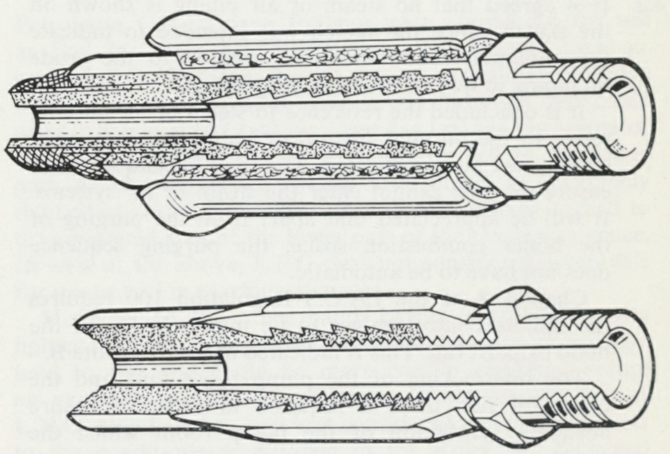

Fig. 2

It is agreed that with the sea inlets located, say, 3–4 metres below sea level it is unlikely that solid ice will be encountered. However, it is an established fact that when navigating in broken ice or pack ice the filters of the sea inlet valves may become choked with slush ice even when the sea inlets are situated well below the surface.

You have included a valuable appendix to your written contribution consisting of a comprehensive list of the various paragraphs contained in a "Guide to the 1978 Rules, Chapters 13, 14 and 15, Piping Systems" including a brief summary of each paragraph to be checked for compliance.

To Mr. Buckle:

I agree that IMCO has recently published a Code of Safety for Dynamically Supported Crafts 1978. I would also add that the U.K. Civil Aviation Authority also has requirements, i.e. "British Hovercraft Safety Requirements" Issue No. 2 dated January 1974.

However, Section 9 of the Paper is based on the Society's requirements for such units as now applied. It may be that the IMCO requirements as applicable will be absorbed into the Society's Rules in due course. Mr. Buckle's comment, however, regarding the use of some "Rule Items" and some

"Code Items" is not understood since the Rule requirements, as indicated, have been in use for some considerable time.

To Mr. B. Wilson:

re: Symbols

As indicated previously, most concerns have their own ideas on this subject. However, I think I can say the following, though not necessarily complete by any means, are commonly used (Fig. 3):

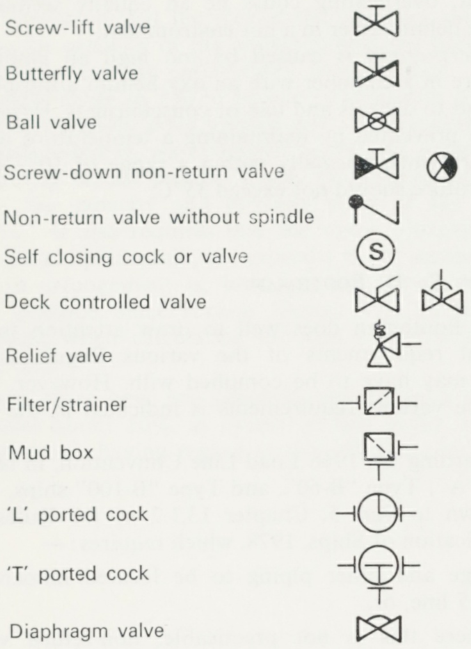

Fig. 3

Screw-lift valve
Butterfly valve
Ball valve
Screw-down non-return valve
Non-return valve without spindle
Self closing cock or valve
Deck controlled valve
Relief valve
Filter/strainer
Mud box
"L" ported cock
"T" ported cock
Diaphragm valve

Light Load Waterline

This expression is, I must confess, an expression commonly known to sea-going personnel, and refers to the conditions in which a ship leaves port *without* cargo, but includes fuel oil, water ballast, consumables etc.

Self Closing Cocks having Parallel Plugs

This implies simply that the body of the plug is parallel over its whole length, as compared with a normal tapered plug. Self closing is, of course, self explanatory. Fig. 4 shows basic sectional views of a tapered and parallel plug.

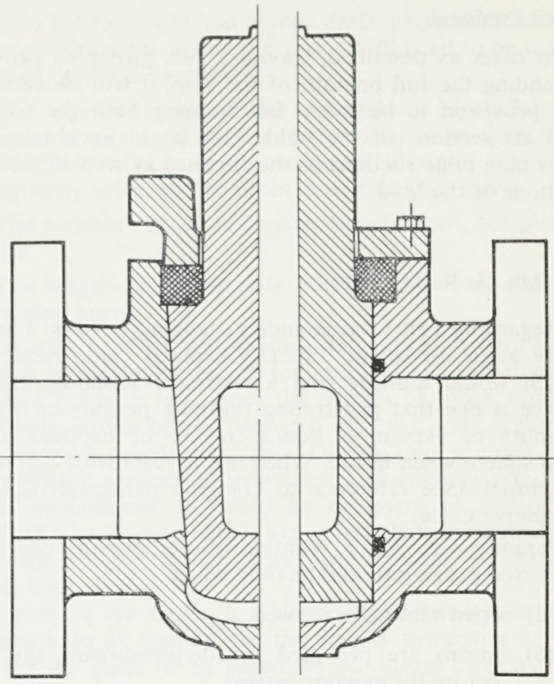

Fig. 4

Tanks

Your comments concerning Part 4, Chapter 1, of the Rules are noted with interest. However, this Chapter and Section refers to structural tanks not separate/independent tanks as referred to in 4.3.17 of my Paper.

The table in Fig. 15 is more akin to the pressure vessel requirements and is based on the maximum unsupported panel breadth.

Fuel Oil in D.B. Tank under Cargo-Oil Tanks

The carriage of fuel oil in double bottom tanks is not looked upon with favour having regard to possible hazard should leakage occur for whatever reason, thus allowing crude (low flush) oil to be admitted to the machinery spaces.

Such an arrangement is contrary to the intention of Part 5, Chapter 15 of the Rules Paragraphs 2.5.1 and 2.5.2, which by implication require that such tanks are to be separated from the crude oil tanks by a cofferdam.

Access to Duct Keels

Part 4, Chapter 11,1.2.6 indicates that access to duct keels, in relation to O.B.O carriers, should be located at intervals not exceeding 60 m, i.e. access will be within 30 m of any part of the tunnel. I consider 30 m (100 feet) is a long way if you are scrambling through a congested duct and suggest the above figures are reduced by 50% which would give a more realistic figure, (i.e. maximum distance between access/exit 15 m). Further, it is considered these accesses should be from the open deck.

Ventilation of Athwartship Stools

Ventilation of athwartship stools, especially in way of corrugations, could be rather complex, in that it essentially requires a branch pipe from the top of each corrugation. Alternatively, the corrugations could be interconnected at the highest point. In some cases, these arthwartship stools could be gas freed by ballasting or the provision of adequate ventilation from the deck. A common practice in offshore floating structures for ventilating pocket areas is to provide a ventilation system within the compartment. This comprises a fan unit circulating the air to such locations.

Hold Drainage

In cases as described, should a box girder be provided extending the full breadth of the ship, it will be necessary for provision to be made for draining both the forward and aft sections of the hold. This could be obtained by providing bilge suctions in the forward as well as the after sections of the hold.

To Mr. J. R. G. Smith:

Regarding restricted sounding/gauging devices, I would draw attention to the IMCO Chemical Code A212 VII, which would indicate that a restricted sounding/gauging device is one that penetrating the tank permits of a small quantity of vapour or liquid only to be exposed to the atmosphere when in use. When not in use the device would be closed. (See reference to Gauging paragraph C.3.9 of the above Code).

Paragraph E. 2.14.3. Venting of the above Code states restricted gauging should be used when:

(a) open venting is allowed

(b) means are provided for de-pressurising the tank before the gauging is used.

In this respect, I see no reason why a sounding pipe of nominal small diameter cannot be considered a restricted device, since opening up after depressurisation would permit only the small surface area of the pipe to be open to the atmosphere.

With regard to sounding arrangements on oil tankers, attention is drawn to Part 5 Chapter 15.5.2.1 of the Rules for the Classification of Ships, which requires that restricted sounding devices are to be used in oil tankers, since the arrangements are to be such that only a limited amount of vapour may escape to the atmosphere WHEN USED. i.e. sounding pipes and as a reserve/emergency means of sounding "Ullage openings" (see Chapter 15.5.2.2).

Subject to the above requirements being complied with, sounding arrangements approved for use on crude oil carriers could be accepted for use on type "C" Chemical tankers.

To Mr. M. R. Skillman:

I do not consider the statement in Paragraph 11.1 as being in conflict with the I.A.C.S. "Unified Requirements" draft, Paragraph 1.102., which requires all equipment "necessary for the safe operation of the unit to be constructed and installed in accordance with the relevant requirements of the Rules and as specified herein", (the reference to the "Rules" being the Classification Society requirements).

Similar requirements are applicable to piping systems—see I.A.C.S, Chapter 1, Section 3, "Piping systems".

With regard to intact and damage stability, as indicated in Chapter C 703 and 705 also Chapter D, Section H and Chapter E, Section 5, supported by Chapter G, Section 3 of I.A.C.S., it is agreed that attention could be drawn to the necessity of preventing cross flooding in the event of damage by means of a suitable general notation in Chapter I of I.A.C.S Unified Rules.

For your further information I consider a similar reference could be included in the IMCO Code for Mobile Offshore Drilling Units (M.O.D.O.'s) draft (DE XIX/6) proposals Chapters IV, V and VI, at present also under consideration.

To Mr. R. Hales:

Mr. Hales quite rightly draws attention to the necessity of preventing over-heating of the diver in a hot environment.

To work efficiently, body temperature should be maintained at:

a. deep body temperature constant at 37 ± 0·5°C (98·4 ± 1°F)

b. mean skin temperature constant at 34·5 ± 0·3°C (94·1 ± 0·5°F)

Although emphasis was given to the need to prevent loss of heat, overheating could be an equally serious hazard for the helium diver in a hot environment.

Hyperthermia is caused by too high an ambient temperature in a chamber with an oxy-helium atmosphere, and can lead to distress and loss of consciousness. Hyperthermia can be prevented by maintaining a temperature within the compartments, normally within a range of 20°–30°C. The temperature should not exceed 35°C.

To Mr. K. D. Boothman:

Mr. Boothman does well to draw attention to the additional requirements of the various Regulatory bodies which may have to be complied with. However, attention to these various requirements is indicated in the Society's Rules.

Regarding the 1966 Load Line Convention, in relation to Type "A", Type "B-60", and Type "B-100" ships, attention is drawn to Part 5, Chapter 13,1.2 of the Rules for the Classification of Ships, 1978, which requires:—

a. bilge and other piping to be located inboard of the B/5 line, or,

b. where this is not practicable, non-return valves or shut-off valves controlled from above the bulkhead deck.

The valves are to be located in the compartment containing the open end of the pipe.

Chemical Carriers: Attention is drawn to Part 4 Chapter 10,1.6 of the Rules for the Classification of Ships, 1978.

Gas Carriers: See Rules for Liquefied Gas Carriers, Chapter 2.4.6.

Passenger Ships: S.O.L.A.S. Piping arrangements are covered in the Society's Rules, see Part 5, Chapter 13,8.1.3.

Regulation 24(6) of the International Convention for the Prevention of Pollution from Ships, 1973 states:—

> Lines of piping which run through cargo tanks in a position less than t_c from the ship's side or less than V_c from the ship's bottom shall be fitted with valves or similar closing devices at the point at which they open into any cargo tank. These valves shall be kept closed at sea at any time when the tanks contain cargo oil, except that they may be opened only for cargo transfer needed for the purpose of trimming the ship.

With reference to the 1966 Load Line Convention, Regulation 27 is applicable to type "A" and "B" ships designed to have empty compartments when loaded to summer load water line, which in the case of some National Authorities, is interpreted to mean water ballast only tanks and by others to mean any tank empty in the fully loaded condition.

In the case of pipe lines located inboard of the B/5 line, no progressive flooding is anticipated since the piping is assumed to remain intact and the valves are closed.

The above is more fully discussed in the Technical Staff Association's Paper "1966 Load Line Conventions and its Implications and Interpretations" by T. A. Simpson, J. M. Bates and L. Beckwith, Paper No. 4, Session 1969–70.

To Mr. M. A. Fingalsen:

It would appear most of the damage referred to has been due to causes outside the Society's control. It will be appreciated that acceptance of Classification is subject to the ship being properly handled. Responsibility of ensuring adequate maintenance and supervision of operation rests with the Owner.

Your suggestion that the size of the air pipes should be related to the capacity of the ballast pumps has been made on previous occasions (MDAPAD records show investigations were made in 1967). Indeed it is known that one Classification Society does require that "the sectional area of air pipes fitted to water ballast tanks and vessels with large capacity ballast pumps, should be determined in relation to the capacity and pressure head of the ballast pumps etc". It also requires that the water velocity in the air pipes should preferably, not exceed 4 m per second.

Such an arrangement is, however, far from simple to apply in practice, since various factors have to be taken into account when calculating the size of air/flow pipes required, viz:—

1. Pumps, when new, are generally capable of a delivery pressure about 10% in excess of the stated pressure. Furthemore, having regard to the difference in suction head between light and loaded draft, particularly on the larger ships, the delivery pressure will need to be calculated on the deepest draft.
2. The types of valves fitted can make a big difference to resistance to flow, e.g. the resistance to flow of a 4″ globe valve is in the region of 12 times that of a butterfly valve, and 50 times that of a sluice valve.
3. The number, types and materials of bends, tee pieces, etc.
4. The lengths and materials of pipes, also any changes in pipe bore.

Accordingly, if such a "theoretical" approach were to be made it would be necessary for individual calculations to be made for each tank since the lengths of pipes, number of fittings, valves bends, reducers, etc., will vary considerably. Having taken the above factors into account, the figure finally arrived at would be a theoretical one. For actual installations, it would be necessary to install the standard size of pipe which is not less than the calculated size, which could in the larger sizes increase by 50 mm (2 ins) steps.

In view of the above, it is not thought that it would be acceptable to all Owners for the Society to require a Rule size for air pipes to be based on the pump capacity and pressure.

It may be relevant to add, that an increase in air pipe sizes alone cannot ensure that a tank will not be damaged. Proper care and precautions must always be taken during pumping operations.

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THE SOLUTION OF ENGINEERING PROBLEMS BY FIELD MEASUREMENT AND ANALYTICAL STUDY

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THE SOLUTION OF ENGINEERING PROBLEMS BY FIELD MEASUREMENT AND ANALYTICAL STUDY

By D. McKINLAY

1 INTRODUCTION

In 1971 the Principal Surveyor in Charge of Technical Investigation Department put forward a paper to the Institute of Marine Engineers on "Marine Machinery Failures". In his paper, the work of the Technical Investigation Department (T.I.D.) was presented as a series of case histories of failures in marine plant and propulsion systems.

In 1975 the merger of two sections took place, namely T.I.D. and Advanced Engineering Services (A.E.S.). A third section (Propulsion Section), was also introduced and a single Department entitled T.I. and A.E.S. was formed. The intention of this paper is to define areas of T.I. and A.E.S work by means of a limited sample of topics. It is also intended to illustrate how current methods and equipment now in use have increased the depth of both analytical and field measurement exercises.

2 FLEXIBLE COUPLINGS

The use of a flexible coupling between engine and gearbox is now widely adopted; knowledge if its flexural properties is fundamental in the design and successful operation of any system.

PLATE 2.1

Failed element from rubber tyre type flexible coupling.

Plate 2.1 shows a failure of a rubber tyre flexible coupling taken from a trawler. Rubber, when subjected to cyclic stress, cracks by fatigue in a fashion analogous to fatigue cracking in metal, although, in addition, it also tends to harden (vulcanise), due to the heat generated. It can be difficult on occasions to decide from the cracking what form of stressing induced the cracks; however, the cracking shown in the photograph on the inner surface of the tyre type coupling is usually associated with excessive cyclic torsional stress. In this case, the bolt holes were also damaged, and from this evidence it was decided that overload was the prime cause of the failure and larger couplings were fitted. These larger couplings also failed in a similar manner and, with this recurrence, the Department was asked to examine the problem in depth.

Calculations had shown that the system should have been acceptable in terms of torsional vibatory torque, but after some preliminary torsional measurements this was found not to be so, and it was decided to check the dynamic coupling stiffness under operating conditions. FIG. 2.1 shows the instrument used to measure coupling twist. This instrument was designed by the Department, manufactured with the help of the Crawley Laboratory workshop and fitted to the coupling by the Investigation Department Surveyors. The device was found to work extremely well and good clear readings of coupling twist were obtained. Corresponding mean and vibratory torques were determined by use of electric resistance strain gauges. Telemetry was used to transmit the signals from the rotating instruments to the recording equipment.

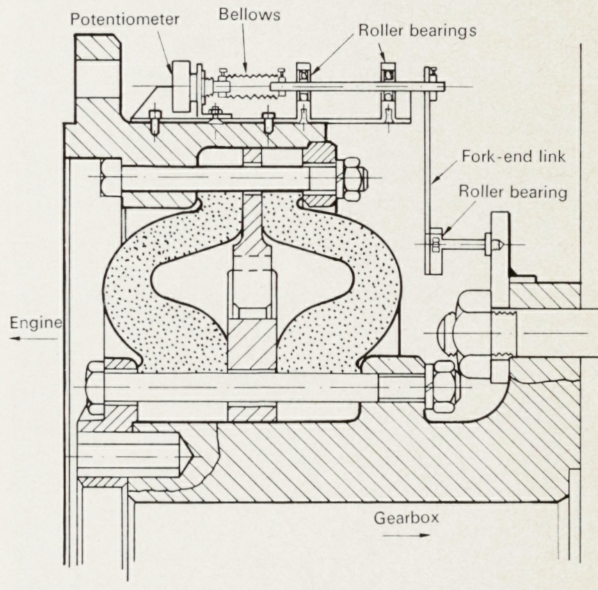

FIG. 2.1

Torsional amplitude measuring device.

FIG. 2.2 shows the measured vibratory torque and also how the torsional characteristics of the system changed due to the change in coupling stiffness with increasing mean torque. This is a well known phenomenon and the Manufacturers supply dynamic stiffness values related to mean torque. However, as can be seen from FIG. 2.3, the coupling

for this particular installation had values of dynamic stiffness considerably higher than specified. Using the measured dynamic stiffness in the original mathematical model, the measured and calculated values of vibratory torque agreed, as can be seen from Fig. 2.4, and since these are excessive, they resulted in failure of the coupling.

A change of flexible coupling to a different type with linear characteristics gave the predicted lower results of

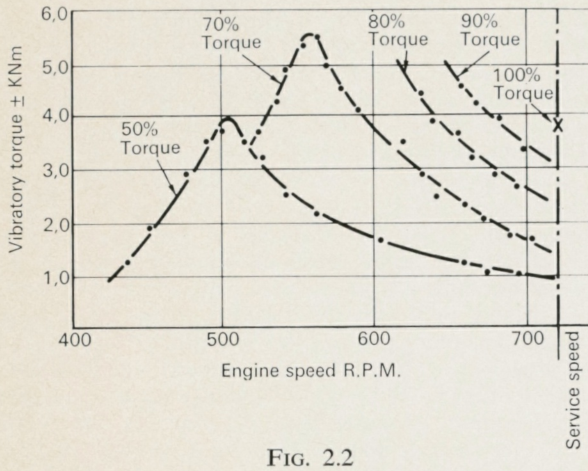

Fig. 2.2

1½ order component of measured vibratory torques in flexible coupling for constant mean transmission torques.

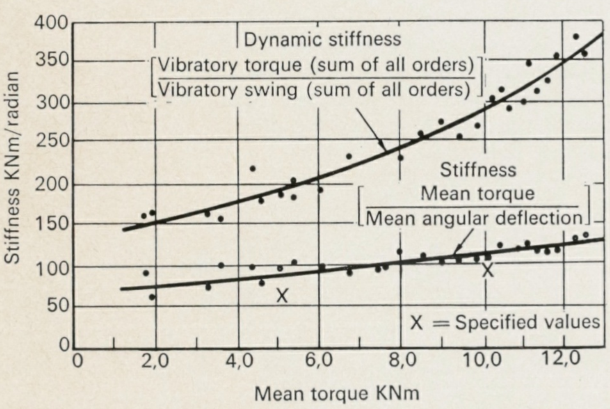

Fig. 2.3

Variation of torsional stiffness with transmission torque.

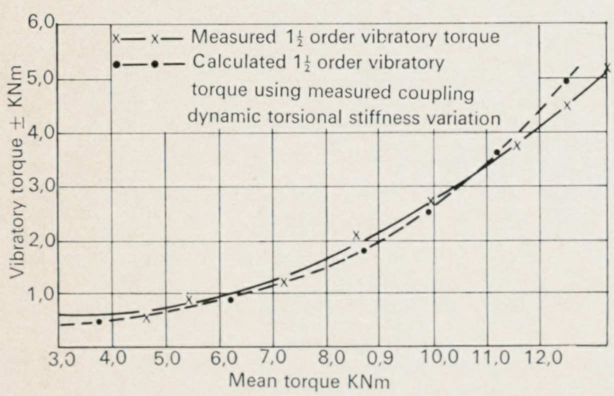

Fig. 2.4

Measured and calculated 1½ order vibratory torques in flexible coupling.

vibratory torque and led to a system giving satisfaction to the Owners.

In another case of an installation using a rubber block type of flexible coupling, torsional measurements of stiffness were taken as part of a long running investigation. The following remarks are limited to this aspect.

In view of the differing form of construction of the coupling the previously described instrument for measuring coupling twist could not be used. In this case the torsional movement of the different elements of the coupling relative to each other was measured by arranging this movement to deflect a small beam. The deflection was determined by measuring strain on the surface of the beam by means of resistance strain gauges. Telemetry methods were again used to transmit the signals from the rotating parts.

Fig. 2.5 shows the results of stiffness plotted against mean torque. The interesting point regarding this coupling was that the amplitude of vibration (i.e. swing), changed the stiffness characteristics. This increase in amplitude was produced by operating the system with one cylinder not firing. The effect is best portrayed in Fig. 2.6, which gives a good indication of the interaction of the three parameters.

The results from the measurements carried out on these different flexible coupling types show clearly how the use to which a coupling is put, can affect the torsional characteristics. This leads to the conclusion that for some

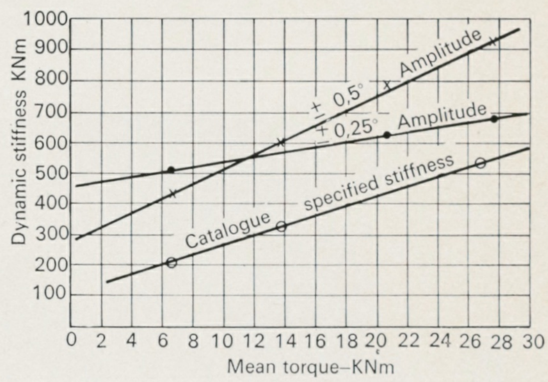

Fig. 2.5

Variation of dynamic stiffness with mean torque and vibratory amplitude.

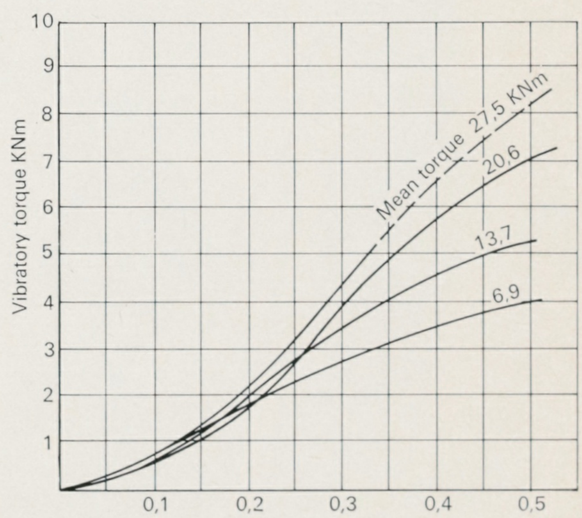

Fig. 2.6

Coupling stiffness characteristics.

installations the choice of flexible coupling type is of paramount importance, and that in some instances the dynamic characteristics specified for the coupling can only be used as a guide.

3 MAIN SHAFT AXIAL AND LATERAL VIBRATION

In addition to measurement and the interpretation of measured results, the Department's work on shafting systems includes much analytical study. Indeed, the Society has provided shaft vibration analysis on a consultancy basis, for some 10 years.

With the increase in high speed ferry and container ships, main shaft axial and lateral vibration have, in recent years, given rise to a need to study in greater depth the problem of accurately predicting critical modes of vibration. The introduction of the finite element program NASTRAN into the Society has given a tool whereby these phenomena can be examined in greater depth. Although further work is required in the application of these techniques they have been used to predict the vibration characteristics for shafting systems where more than one degree of freedom has to be investigated.

For the system shown in Fig. 3.1, the lateral vibration normal modes and amplitude response to propeller excitation have been calculated and are shown in Figs. 3.1 and 3.2. It can be seen that the third mode of vibration at 15 Hz. is dependent upon the mass and stiffness characteristics of the "A" bracket. Without the use of the finite element approach to model the "A" bracket, this mode of vibration would not have been predicted. Coupling between the shaft and the "A" bracket posed no problem for this particular ship as a water lubricated bearing was used. However, oil film properties have been necessary in other investigations and when required the Department utilises the computer to predict oil film stiffness and the damping matrix, including cross-coupling terms.

The propeller plays two important parts in the response of the system. For the normal mode analysis the mass and inertia values of the propeller and entrained water have to be known. The former is normally supplied by the manufacturers but the latter is produced by a suite of programs held by the Society. The hydrodynamic coefficients are calculated by lifting surface theory from blade geometry. The output is supplied as a 6 × 6 mass and damping matrix. For the response calculations such as predicting amplitudes of propeller movement, fluctuating bearing forces etc. the same suite of programs produces forcing coefficients for the six modal directions from full scale or model wake data. Thus it can be appreciated that combining these complex matrices with a shafting and "A" bracket configuration, leads to a requirement for an analysis that goes well beyond the standard Holzer tabular method. For this particular installation the calculations indicated a need for re-design and a recommendation to change the number of propeller blades was made.

Even with these sophisticated calculation techniques, checking by measurement is desirable in many cases, the more service experience we can amass the more we can improve the accuracy of our mathematical models. The confirmation of natural frequencies can often be easily obtained with dynamic bending measurement by strain

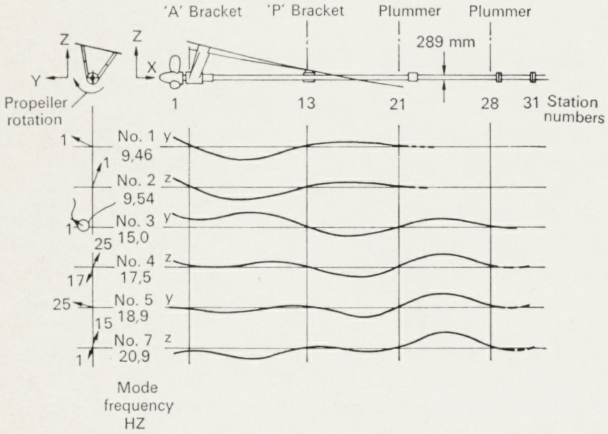

Fig. 3.1

Lateral vibration mode shapes.

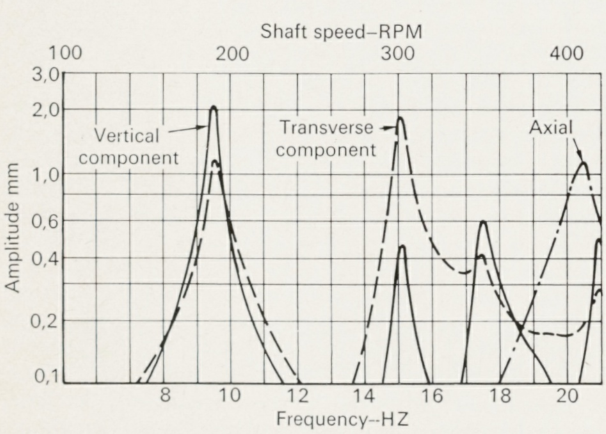

Fig. 3.2

Calculated amplitude at propeller (Position 1).

Plate 3.1

Proximity probe external to aft stern bearing.

gauges on the shaft inboard. However, the external measurement of amplitude in way of the after oil seal is desirable to confirm acceptance of operating a shafting system at speeds approaching a critical lateral vibration. The photograph illustrated in plate 3.1 shows the proximity probe and accelerometer in position covered by a proofing compound.

Steel conduit carries the signal cables to the measuring instrumentation situated inside the ship where, if necessary, analysis can be carried out as the data is being collected.

On a different class of ship, the axial mode of vibration was considered likely to be a problem. The configuration is shown in Fig. 3.3, and is typical for a direct drive vessel. The crankshaft is a very complex length of shaft for which, in the past, several attempts at producing empirical methods of estimating axial stiffness have been made. With the facilities available within NASTRAN an approach has been developed to model a single crankthrow element for an engine type and by computer manipulation a full crankshaft can be built up for any number of cylinders once the configuration of the crankshaft throws is known.

The relative mode shapes for the first and second predicted natural frequencies are plotted in Fig. 3.3. Mode 1 is the thrust block mode and as such is dependent upon thrust block stiffness and mass of the system. Mode 2 is a crankshaft/shafting mode and is dependent upon the stiffness of the crankshaft.

Calculations were repeated varying the thrust block stiffness between known limits. By plotting resonant frequencies against shaft speed, excitation orders can be superimposed, (see Fig. 3.4). Using this graph in conjunction with a phase-vector histogram shown in Fig. 3.5, produced from the vector summation of the crankshaft mode shape, it can be seen that the 4-bladed propeller is unlikely to excite an

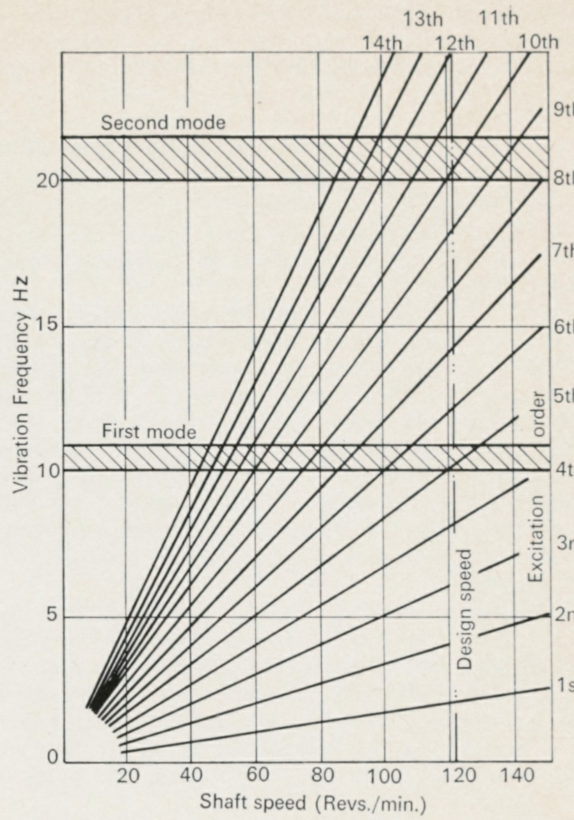

Fig. 3.4

Critical speed spectrum.

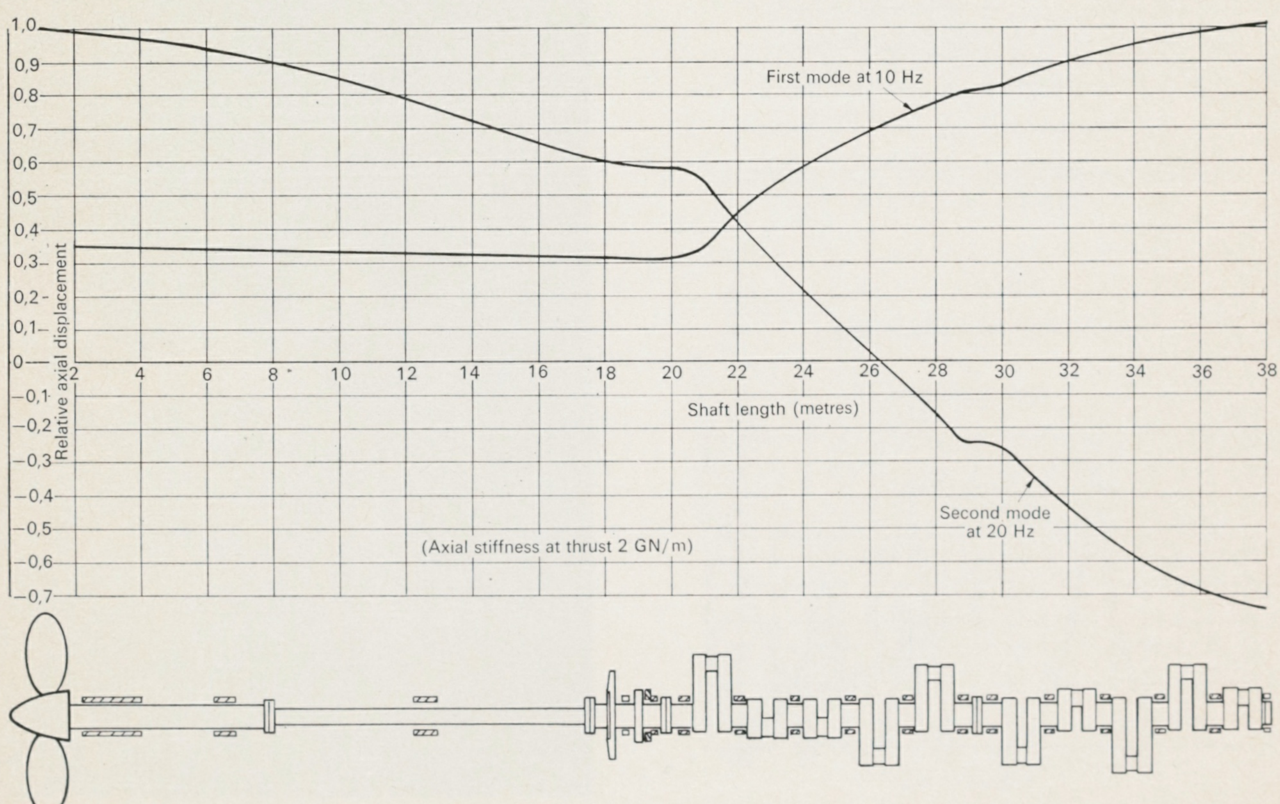

Fig. 3.3

Axial vibration mode shapes.

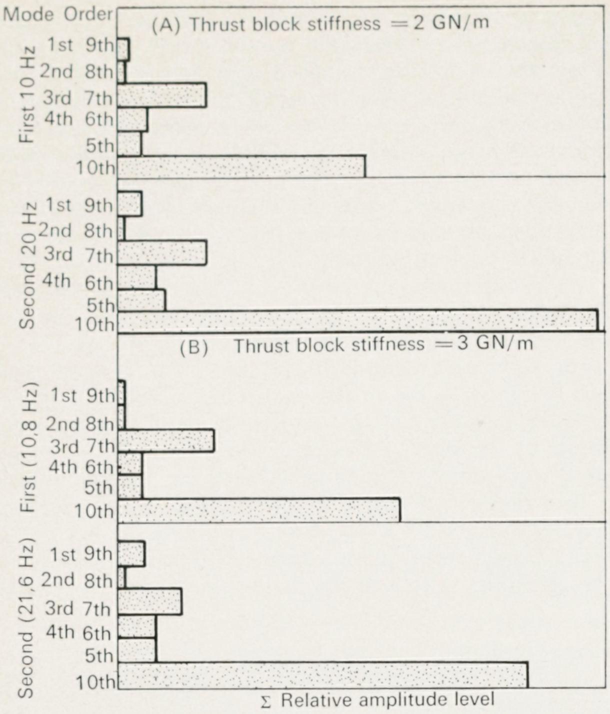

FIG. 3.5

Crankshaft phase-vector diagrams.

axial resonance. However, the 5th and 10th order engine harmonics could excite the first and second mode axial resonances respectively. Referring to the histogram, the excitation level for the 5th order fundamental is small and unlikely to predominate. The same cannot, of course, be said for the 10th order which is a maximum (not surprising as it is a 10 cylinder engine). Measurements have been recommended for this installation and if the amplitudes are found to be excessive an axial damper will be required.

The following results from an analysis of a container ship shafting system are presented to illustrate the accuracy being achieved using the finite element method. The installation consisted of a length of straight shafting coupled directly to a 4-bladed propeller and an eight cylinder engine. Three methods of predicting the resonant frequencies were adopted and each gave the same value of fundamental frequency, 11.3 Hz.

For the second mode, however, the three methods gave differing results. Method 1 used a conventional Holzer type approach with the crankshaft stiffness calculated using a well known empirical method. This gave a natural frequency of 16.2 Hz. Method 2 used the same approach but with the mass elastic data of the crankshaft supplied by the engine builder, and gave a frequency of 16.0 Hz. Method 3 used NASTRAN with the crankshaft axial geometry modelled by BAR elements as described previously, and gave a much lower frequency of 14.7 Hz.

It was predicted that both modes would be excited by the engine 8th order and the propeller bladed 2nd order, within the operating speed range. Measurements taken from the vessel gave criticals at 11.1 and 14.2 Hz. which correspond well with the finite element model at the expected value of thrust stiffness of 3GN/M. Fortunately, the corresponding amplitudes were not considered excessive for this installation and a damper was not required.

The measurements of axial vibration in these cases have been undertaken by the Department and the standard method is illustrated in plate 3.2. The displacement of the shaft relative to the hull structure is measured by a proximity probe (non-contacting). This method requires that the structure itself is not vibrating. For systems where structural vibration is thought to be likely (most marine installations), an amplitude calibrated velocity transducer is placed at the probe position and the signals from the two devices are simultaneously recorded.

The recordings are then analysed using either digital methods or the Department's real time analyser.

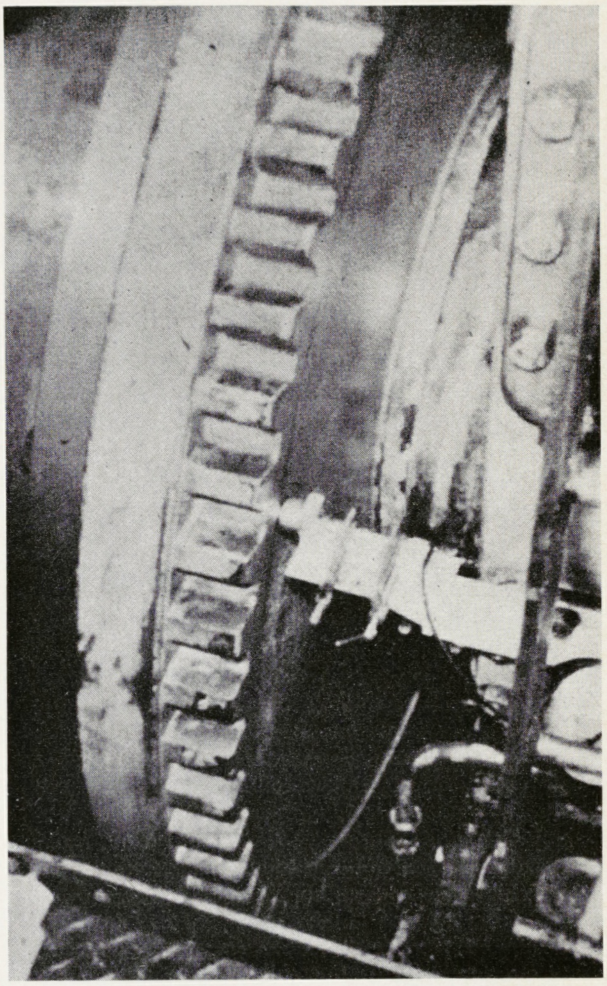

PLATE 3.2

Axial measurement using proximity probe.

4 STEAM PIPES

There have been several vessels with problems of fractures in the main steam lines, and when the Department has been asked to help we have been most grateful for the assistance of our colleagues at Crawley Laboratory. In several cases cracking has been found to be a recurrent phenomenon affecting a particular section of the pipe which has been repeatedly repaired by veeing out defects and welding. The underlying causes of the problems can in these circumstances remain unclear and when considering such repairs it is useful to note that in one difficult case the Society's metallurgists identified the mode of failure from a small sliver of material cut from the pipe to contain a section of the fracture.

This escalation of main steam line problems has taken two forms. One is due to thermal fatigue which appears as craze cracking in the bore of the pipe and can result in failure. The other form of failure concerns stub pieces

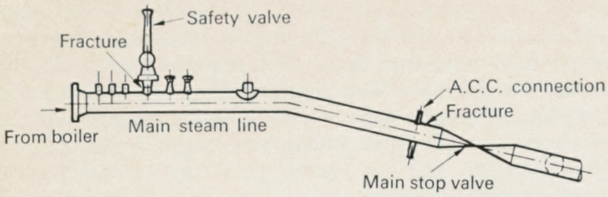

FIG. 4.1

Main steam line.

welded to the main line. A piping system which unfortunately experienced both these problems is illustrated in FIG. 4.1. In this case a rather dangerous situation arose after the superheat safety valve stub cracked due to corrosion fatigue and longstanding cracks suddenly opened under the additional loads applied when the valve operated. (See plate 4.1).

As the fractures had occurred in the thinned portion of the original stub, a new stub of greater wall thickness was fitted. To determine the cyclic stresses causing the failure, high temperature strain gauges were welded to the new stub by a Technical Investigation Department Surveyor. It is interesting to note that the temperature of the steam in the pipe was about 520°C and even at this high temperature these special strain gauges performed satisfactorily.

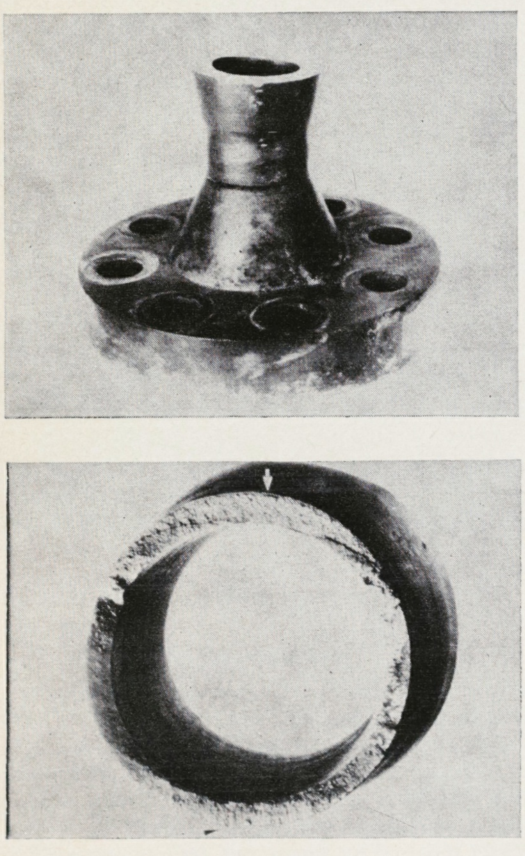

PLATE 4.1

Fracture of safety valve stub pipe.

High stresses were measured when the safety valve lifted and, in addition, vibratory stresses due to propeller excited vibration were present. The installation of the waste steam pipe had been carried out to provide the simplest pipe run to clear the engine room platform structure. This resulted in a lever arm of some 500 mm between the waste steam pipe and the valve, which in turn increased the applied bending moments generated by the steam reaction forces when the valve lifted. The loading conditions were further aggravated by the incorrect setting of the valve blow-down control ring. Rapid oscillation of the valve occurred which produced large fluctuating reaction forces and bending stresses in the valve stub pipe. The investigation showed that the propeller excited vibration stresses were sufficient to propagate the cracks initiated by the steam reaction forces.

As well as thickening up the stub, a stool was fitted under the waste steam pipe to restrict its deflection and thus limit the bending moment on the valve stub due to the reaction force. Care was required in the design of the stool which was clamped to the main steam pipe in order to provide sufficient rigidity and to ensure the large thermal movements of the safety valve relative to the waste steam pipe were accommodated without inducing any additional loads.

In a number of cases, thermal fatigue mentioned above has been caused by water droplets striking the hot internal wall of main steam pipes. Present experience indicates that this generally occurs in the main line adjacent to external

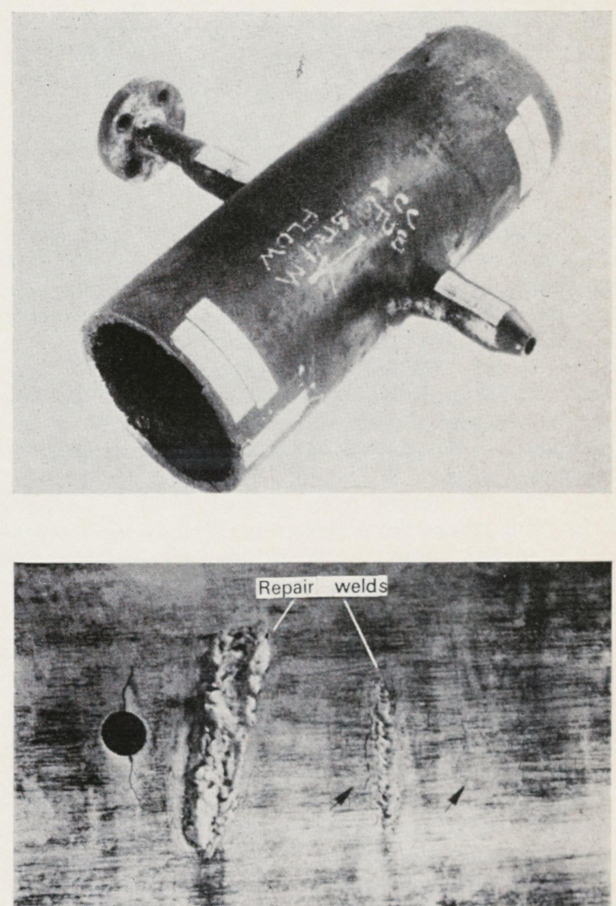

PLATE 4.2

Fracture in way of A.C.C. connection.

de-superheaters and down stream of Automation Combustion Control (A.C.C.) connections. In the cases of external de-superheaters it is believed this has been due to leakage from the water supply. For the system illustrated, fractures were found in the A.C.C. connection and in the top of the main line immediately down stream (plate 4.2). These lines normally do not have any steam flow through them and, if

they are long and rise above the main steam line, condensation occurs which can run down into the main line. It is likely that any long horizontal run of pipe magnifies this phenomenon as water will lie in this section and be displaced, in large quantities, back into the main line with rolling and pitching of the vessel. The solution is to place the pressure transducer below the main steam line or ensure that there is continuous flow of steam through the line. There is no reason why this should be limited to A.C.C. connections as any dead leg taken off a main steam line could cause this problem.

5 HULL VIBRATION

The Department's interest is not restricted to ship's main machinery. Frequently the effects of vibration on hull structure and crew comfort have to be examined and in recent years there has been a marked increase in the incidence of vibration problems arising from the interaction of the propeller and the hull.

The propeller cannot be considered in isolation when endeavouring to solve a particular problem associated with its operation. In all but a relatively few cases the solution is to be found in the complex interactions involved between the hull profile, the induced wake field and the propeller itself.

The hull surface pressures resulting from the passage of each blade and its associated pressure field are frequently a cause for concern. Fig. 5.1, shows an example of the pressure impulses recorded on a ferry having a constant shaft speed controllable pitch propeller installation. It can be seen that there is a sharp increase in the slope of the

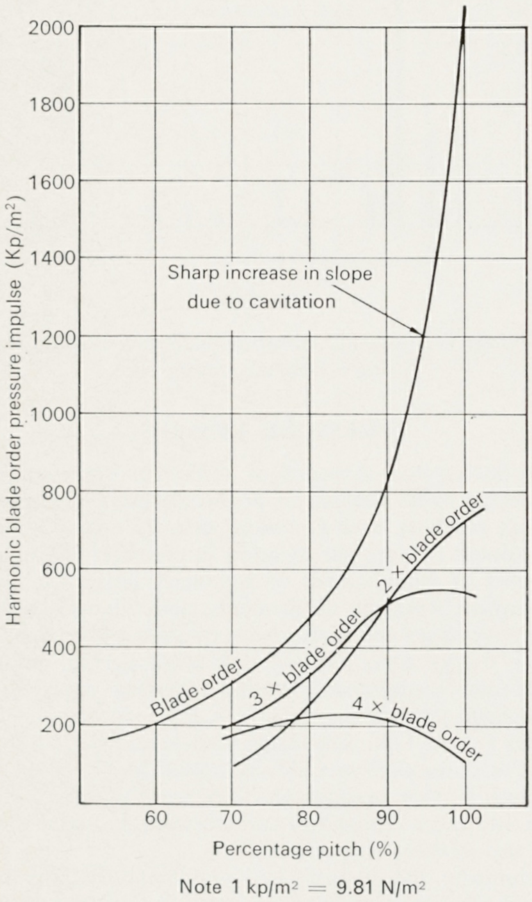

Fig. 5.1

Effect of propeller cavitation on hull pressure impulses.

pressure curve due to the effects of cavitation occurring on the propeller blades. Generally, values of these pressure impulses do not cause concern provided the blade order magnitudes are below a range of about 8 kN/m^2 to about 12 kN/m^2. The precise value depends primarily upon the structural design of the vessel. In the example shown in the figure, it can be seen that for all the blade order harmonics greater than the first, the pressure impulses are of a smaller magnitude than for the first. This however, is not always the case and particular attention has to be paid to those cases where the second and third harmonic components are of greater magnitude, since these types of spectra are often indicative of the likelihood of structural damage to the ship. Indeed, this has even been found to be the case where the magnitudes of these higher harmonics have not reached the limiting range mentioned above.

In cases where vibration has been found to be a problem there are usually several methods by which a reduction of the vibration levels can be effected. From the many methods available, two are singled out below for specific discussion, together with examples of their application.

Hull vortex cavitation has been found to exist on certain types of vessel. Generally, the types of vessel which appear to have been most affected by this problem are ships having a single screw in association with a hull having a large frame half angle above and forward of the propeller coupled with comparatively small tip clearances. The frame half angle above the propeller being of the order of some 80 degrees and greater. In some, but not all cases, there has been a characteristic patch of cavitation erosion found on the hull surface above and slightly forward of the propeller corresponding in general to the shortest path between the propeller tip and the hull surface.

Success has been achieved in all cases of known and suspected propeller hull vortex cavitation by the fitting of a single fin of the type shown in Fig. 5.2. An example of the advantage gained by the use of such a fin when applied to a coaster which had been suffering from the effects of this type of cavitation is shown in Fig. 5.3.

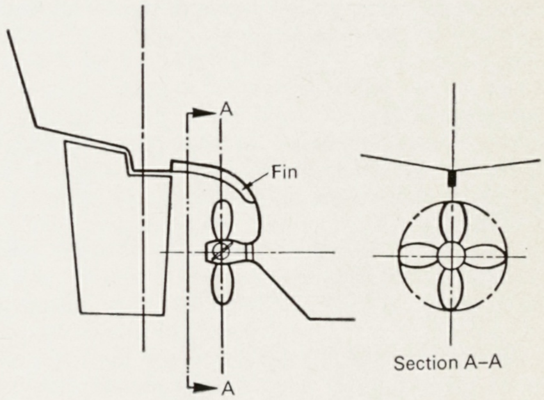

Fig. 5.2

Type of fin commonly used for propeller hull vortex cavitation.

On another occasion, when measurements indicated that this type of cavitation existed on a container ship, a similar fin was fitted but also extended further down the propeller aperture toward the shaft centreline in an attempt to relieve the effects of a poor stern post design.

Subsequent to the fitting of the fin, the levels of vibration experienced by the ship's crew have been so dramatically reduced that repeat measurements were not considered necessary by the Owners. In cases where there has been

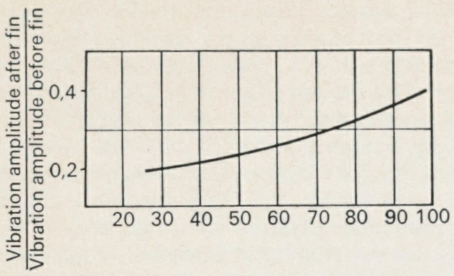

FIG. 5.3

Example of improvement gained by use of a propeller hull vortex fin.

a marked reduction in the vibration there has also been a corresponding reduction in the noise levels encountered in the ship. In one case of a bulk carrier this amounted to a reduction of 5 dBA.

Other types of fin configuration are shown in FIG. 5.4. These fall broadly speaking into two catagories, namely those for correcting the effects of a dead water region at the top of the propeller aperture and those for suppressing the characteristic downward flow of water forming a troublesome bilge vortex, see FIG. 5.5. The design of these types of fin is based upon exhaustive design and model tests and as such is normally carried out by specialists.

An example of the improvement which can be gained from the use of fins is shown in FIG. 5.6, and indicates the change in the harmonic vibration spectrum effected by fitting fins to an L.P.G. carrier having a 4-bladed propeller. Although in this case there resulted a slight increase in the amplitudes of the higher orders, the reduction in the blade and blade minus one orders was sufficient to give a considerably improved vibration characteristic for the ship.

The detailed analysis shown in FIG. 5.6, is of particular interest since use has been made of the Department's in-house real time spectral analyser. This recent addition to the Department's armoury of data logging, computing and

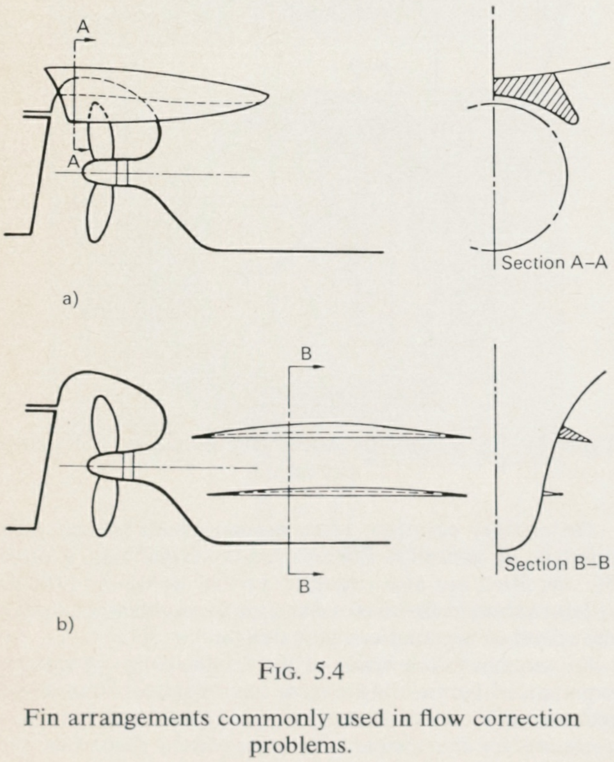

FIG. 5.4

Fin arrangements commonly used in flow correction problems.

analysing equipment has freed the Surveyors from the tedious digitising techniques previously used for multiple channel recordings of complex waveforms.

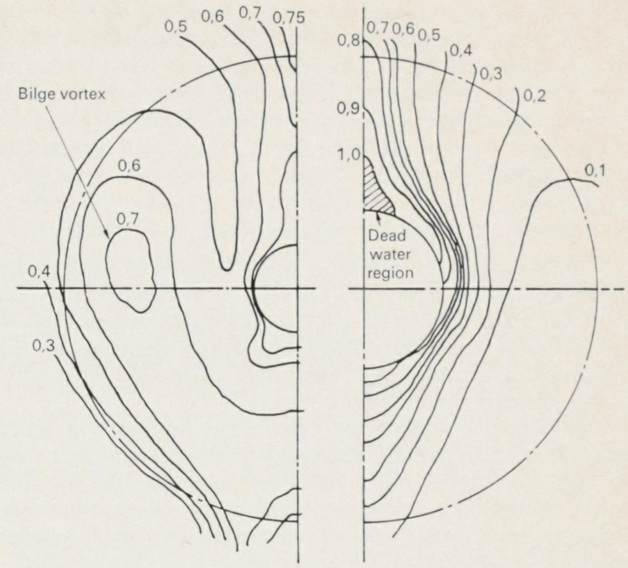

FIG. 5.5

Wake fields associated with the use of fins.

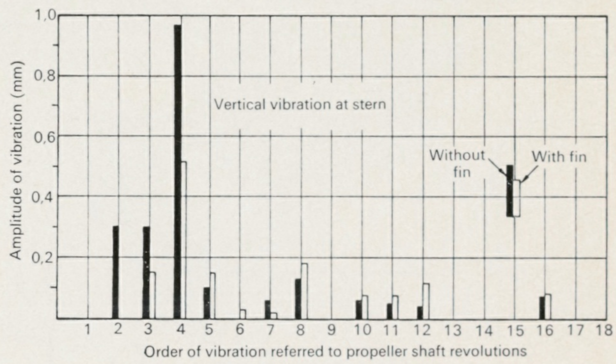

FIG. 5.6

Change in harmonic vibration spectrum effected by fitting a flow correcting fin.

6 PRESSURE VESSELS

The Society has a record of successful implementation of practical stress analysis of pressure vessels under test in the field reaching back for more than 25 years. With the development of post-war aviation in the early 1950's came a number of wind tunnels of advanced design for use by Government Research departments, and this was followed in the later fifties and early sixties by the rapidly expanding nuclear energy field. During this latter period, some 30 reactor and containment vessels, including research and development projects for the U.K.A.E.A. commercial power reactors for the U.K. generating boards, and the two British export reactors were successfully tested. More recent years have seen further involvement with wind tunnels (of both recent and older design and construction) and with the oil, LNG and offshore industries.

Technically, the Department's major contribution to the state of the strain gauging art was, in earlier years, the development of what was then primarily a laboratory or workshop technique to the stage where strain gauges could successfully be employed on a fabrication or construction

site, under a wide variety of environmental and test conditions which were generally (as an intentional under-statement) less than favourable. More recent developments have centred on substantial improvements in data acquisition and interpretation techniques, involving computer hardware and software applications and embracing other analogue transducers in addition to strain gauges.

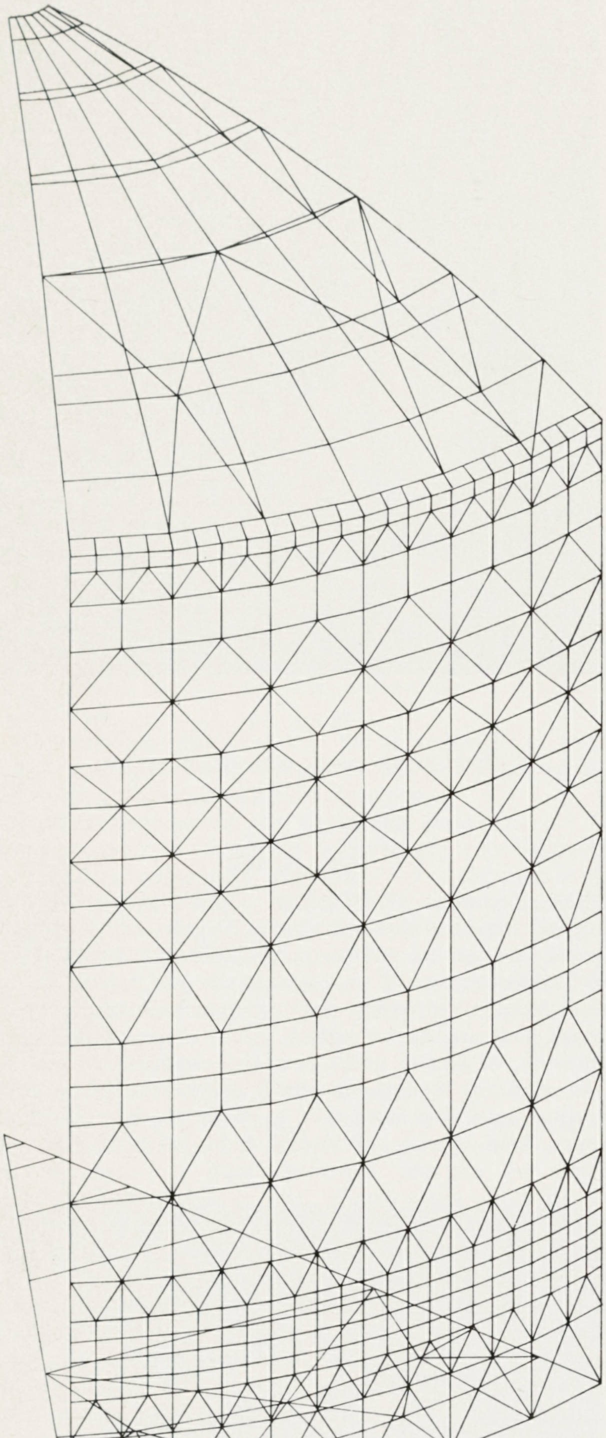

FIG. 6.1

Model of gas storage tank.

With the techniques the department has developed in transducer application combined with data acquisition, we fully expect better than 99½% of the transducers to give satisfactory data.

Analytically, the Society has not stagnated. Indeed, with the advent of finite element techniques, large scale static stress analysis of pressure vessels has been undertaken by the Department. This involves the building of a mathematical model from plate elements with the necessary constraints to simulate the loading conditions. These include hydraulic, gas, thermal and applied loadings. As an illustration, one such mathematical representation of a gas storage tank is shown in FIG. 6.1.

In terms of scale, the largest commitment so far undertaken by the Society was the pneumatic testing of the 5M Low Speed Wind Tunnel, where the complexity and extent of the structure were such as to demand utilisation of all but 100 of the total 1600-channel capacity of the department's data logging equipment. The main objectives of the test were threefold, namely:

> To establish, with minimisation of potential hazard, that the internal pressure of the tunnel could be incrementally raised to its required test value.
>
> To determine whether the actual stresses in the vessel under design conditions were such as to be acceptable from the standpoint of the appropriate pressure code.
>
> To obtain maximum surface stress information in order that the subsequent performance of the tunnel in a fatigue context could be assessed.

To achieve each objective successfully, practical analysis by way of strain gauges was essential. With a hydraulic test rendered out of court due to the effect of weight of water on the foundations, the only alternative was the potentially explosive pneumatic test. This could have jeopardized the integrity not only of the tunnel but also the adjacent buildings. A sensitive and accurate test control, such as could be provided only by the type of expertise that the Society can bring to bear, was therefore mandatory. The numerical value requirements of the other two main objectives also demanded the employment of strain gauges.

In addition to safety and accuracy, a further stringent requirement (aimed at reducing the test period, and hence the need for safety precautions to a minimum), was the response time (stipulated as 3 minutes), for the acquisition of the results from 1500 transducers and their interpretation and presentation in meaningful engineering terms. To this end computer software was specially devised by the Society. Plate 6.1 shows the underside of the wind tunnel with the scanner instrument for some of the transducers. The signals were fed from this to the central processor which can be seen in Plate 6.2.

The test itself was carried out in two main phases, since to replicate design conditions it was necessary to subject the inner spherical working section to both internal and external pressure. For the remainder of the structure, the pressure boundaries were identical during both phases. In the event the tunnel was safely brought to its test pressure for both phases, and satisfactory performances in relation to shakedown, code stresses, and fatigue were demonstrated. Summarizing, only two of the 1500 channels were thought not to have been reliable. Recorded stress ranges at all locations except those affected by the change of pressure boundary were repeatable to within 3.0 kN/m^2. Satisfactory response times were achieved throughout, and no problems were experienced with computer hardware and software.

A second example of this type of investigation was carried out at extremely short notice on a test specimen simulating a proposed repair to a Submerged Oil Pipeline.

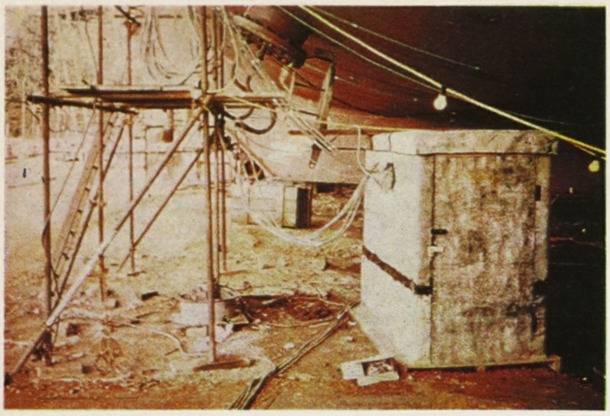

Plate 6.1

Wind tunnel with strain gauge scanner instrument.

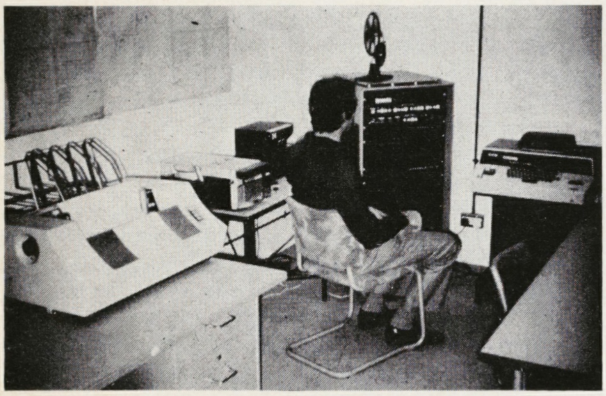

Plate 6.2

Central processor.

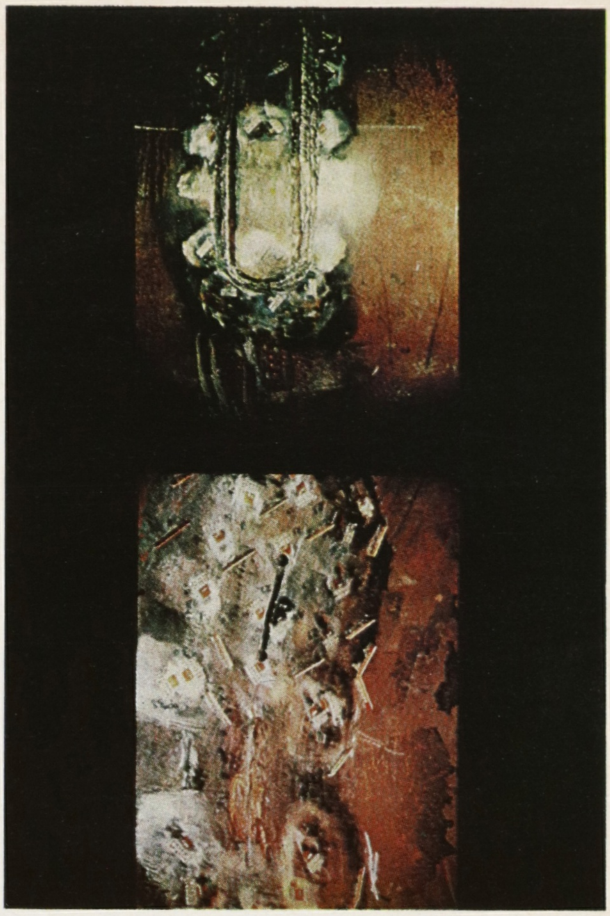

Plate 6.3

Weld repair model with strain gauges.

Plate 6.3. Objectives included not only the monitoring, recording and suitability assessment of stress levels but also the subjection of the specimen to fatigue cycling thus duplicating anticipated actual conditions. Test pressures (hydraulic) involved here were of the order of 17.0MN/m^2. The number of measuring points was relatively small requiring only 120 channels of scanning capacity but the number of sets of readings required to demonstrate cyclic performance was usually large. The involvement of computerized equipment was therefore essential, resulting in a 30 second response time for the production of a complete print-out of principal, meridional and circumferential stresses, together with equivalent uniaxial strain, from all gauges.

The test demonstrated conclusively rapid shakedown to purely elastic conditions, satisfactory stress levels at design pressure and the adequacy of the fatigue life of the patch weld, and it was concluded that, provided the geometry and integrity of the test specimen were reproduced by the actual repair, the latter would be acceptable for the prescribed service conditions under the sea.

The Department responded to this situation in a very short period of time and was able to provide the results involving the acquisition and interpretation of no fewer than 45,000 transducer readings within a week from initial notification of the requirement.

7 GEARING

The Technical Investigation Department of Lloyd's Register has been in existence for 30 years and during this period has carried out many in depth investigations into problems encountered on gears. In the past 5 years the use of techniques employing strain gauges with telemetry has meant that we have learned much more of the actual behaviour of gearing under operating conditions at sea.

In addition to data on stress distribution along teeth, strain gauges have been used to study the effects of pitch errors, load sharing of locked train gearboxes, and the effects of external influences such as alignment and vibration. As gears usually have a hunting tooth, a strain gauge on a given tooth will, in time, mesh with all teeth of the mating element. This characteristic can be used to isolate many different effects. For example, with strain gauges placed on the wheel, it is possible to study the effects of engine-excited torsional vibration on the gear teeth of a diesel drive. Alternatively, with strain gauges on a pinion, propeller-induced effects can be examined. Both techniques have their place, but for practical reasons, strain gauging of pinions is much more difficult and hence not so frequently carried out. The present approach is to use strain gauges in a full Wheatstone bridge configuration connected to a frequency modulated telemetry system. The gauges are distributed axially and circumferentially so that only one gauge is meshing at a particular instant. The demodulated signal received from the rotating transmitter is fed to an amplifier and thence to an ultra-violet

recorder. The recording incorporates a timing signal and shaft revolutions are also displayed on the recorder trace to facilitate analysis.

The installation procedure involved is lengthy and often requires the Surveyor to apply laboratory techniques under cramped conditions. This is best illustrated by plate 7.1, which shows the application of strain gauges through the coverplate on a large turbine installation.

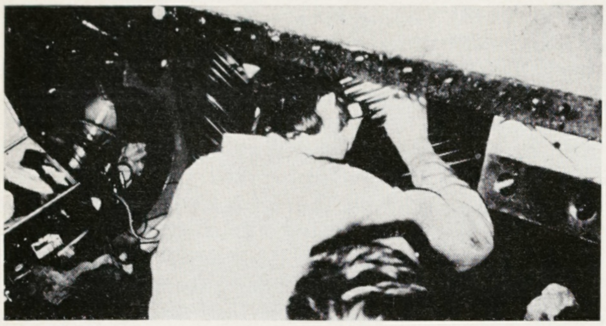

PLATE 7.1

Application of strain gauges through cover plate on a V.L.C.C. gearbox.

Plate 7.2 shows the wiring on a main wheel and the telemetry set. A more sophisticated arrangement can be seen in plate 7.3 where the complete transmitting equipment is miniaturised and housed in a dynamically balanced ring attached to the LP pinion of a turbine set. A less sophisticated arrangement on a diesel drive is shown on plate 7.4. Note the large battery pack needed when long running time is expected.

These photographs show that the arrangement of strain gauges and transmitting equipment has to be individually tailored to suit each installation measured.

Initial calibration of the equipment is carried out by shunting the strain gauges with a known electrical resistance to simulate strain and the response is fed to the ultra-violet recorder. When taking strain recordings for a particular condition of load and speed, sufficient recorder trace is generally run off to ensure that each gauge has meshed with all the teeth of the mating element. The strain records are analysed by the extensive data-handling facilities available in the department, using a suite of programs specially developed for the purpose.

The effects of external influences on a gearbox have been a constant cause of concern to the Department having regard to the number of cases where bad alignment or poor

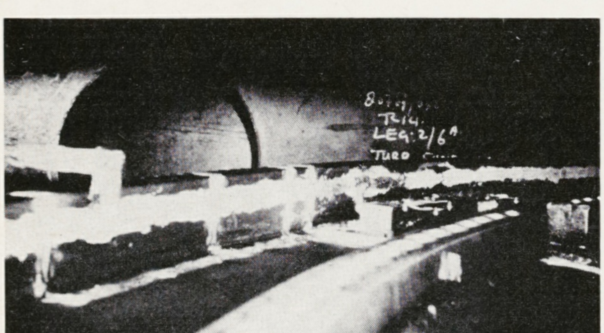

PLATE 7.2

Wiring arrangement on a V.L.C.C. main wheel.

design of the system has resulted in damage within the gearbox. Since the use of rational alignment has become widespread, the cases of gear pitting and tooth breakage associated solely with external influences and badly designed systems have become negligible. The Department can take some credit for this as it has been producing rational alignment configurations on a consultancy basis for over ten years. However, when a gear problem does exist on a vessel, it is still necessary to establish, by measurement and calculation, what effect the external influences have on the gearing.

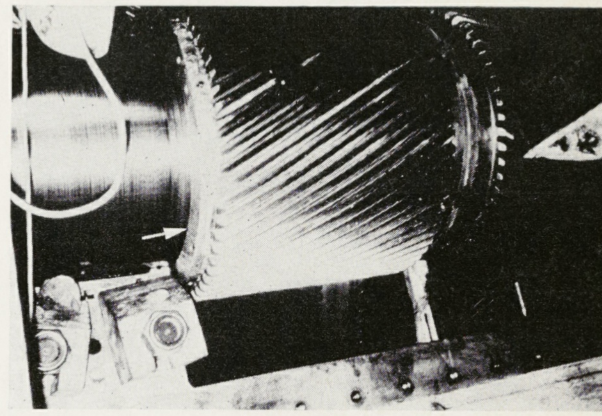

PLATE 7.3

Miniaturised transmitting equipment in purpose built ring attached to an L.P. pinion of a turbine set.

The method described of strain gauging gear teeth has been used many times for this work. It is an ideal tool to establish the facts.

For example, to investigate the effects of hull deflection changes on a gearbox, the department carried out a very large research programme on a large tanker. This work involved the measurement of gear tooth bending strain and its relation to changes in hull deflection and bull wheel journal bearing loads.

In addition to the instrumentation placed in the gearbox itself, the main shaft line was instrumented with six sets of strain gauges and associated telemetry at selected stations along the shaft to measure bending moment, both statically and dynamically. Electronic transducers were used to measure between a datum, formed by a series of tubes, and the hull structure. The results of these hull and shafting measurements, when processed by the department's data analysis techniques, enabled hull deflection and main bearing loads to be established.

A sample of the results of tooth strain measurements from this project is presented in FIG. 7.1. The graphs in this figure are of tooth strain, plotted as a stress analogue. They show the variation along the bull wheel helix for each individual pinion as it meshes with the wheel. The different conditions of shaft speed and hull loading are detailed in the figure. The corresponding changes in the hull are given in FIG. 7.2, and it can be seen that the maximum vertical change of the gearbox is about 1 mm. The results of the calculations of bull wheel journal vertical loads are given in FIG. 7.3 for both the dynamic and the static conditions for the two different hull loadings. It should be appreciated that these results are only a small part of the work carried out, but even to present these, large quantities of data had to be handled.

Examination of these figures shows that the change from loaded to ballast condition has had little effect on this well aligned system.

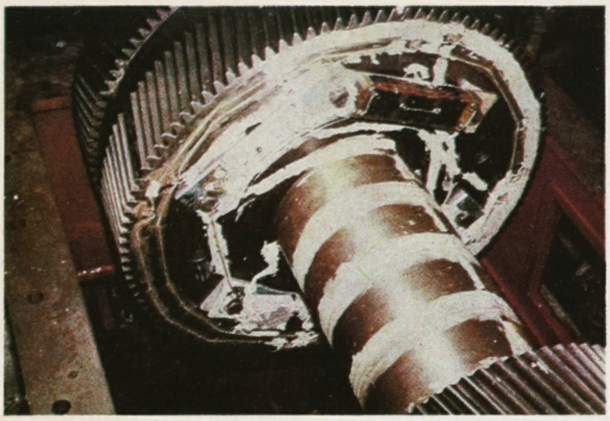

PLATE 7.4

Telemetry set up on small medium speed diesel engine driven gearbox.

The strain gauge results typified in FIG. 7.1, can be analysed by mathematical methods to distinguish between the effects of different phenomena on the gear teeth. The Department has developed computer software which, with a minimum of human effort enables the analysis to be handled quickly to produce the components of mean stress, helix mismatch, thust and alignment.

Where more than two gauge positions are used along the length of one helix, the mean measured distributions of stress are modelled by fitting first order polynomial load functions to the trial data in the least squares sense and, giving each data point equal weight, the components of the tooth loading can be found. For the subject vessel these are plotted on a base of transmission torque, in FIG. 7.4.

These results are most interesting. They show that in the case of the LP pinion the effect of helix mismatch at full power is about 30% of the mean stress. It is obvious that helix mismatch cannot be affected by external or internal loads and this difference can only be improved by re-machining the gears.

By study of FIG. 7.3, it can be seen that the main bearing loads show a load differential of 34 kN heavy aft (ship loaded), and that when full power is reached this load differential changes to 30 kN heavy forward. On sea trials, this result was achieved only after ballasting the vessel down to full draught. We have noted on several large tankers that shaft alignment stabilises only after the vessel has been ballasted down to the full load condition, and in view of this, there is a case that shaft alignments of these large vessels should be checked at a very early stage of operation.

The excellent dynamic alignment finally achieved in the foregoing ship is substantiated by the tooth bending stress component of alignment. It can be seen in FIG. 7.4, that the variation is small compared with change in mean stress.

One interesting result from this vessel was the effect of filling the large afterpeak to its full capacity of 1600 tons. This hull operation modified the load distribution on the gear teeth by 6% of the mean strain; up at one end, down at the other. To put this in perspective, an adjustment of 0.25 mm to the plummer block aft of the gearbox was needed to produce the same change. However, an internal pinion to wheel adjustment of only 0.1 mm across one helix in the plane of action had the same effect. The limited magnitude of the change in mean strain is encouraging.

From the results it was concluded that the interaction of ship's loading and hull movement on this vessel affected the main shaft alignment to a measurable degree but, provided a good alignment exists initially, the effect on gear tooth loading is considered to be completely outweighed by inaccuracies within the gearbox itself.

It is of interest to note that on practically every new main steam turbine installation, including the one reported here, where the department has used the techniques described, the trials have been stopped to re-align the pinions to the main wheel on the basis of the strain gauge readings. This indicates that our present methods of assessing meshing by hard and soft marking do not necessarily place the gearboxes in the optimum running condition.

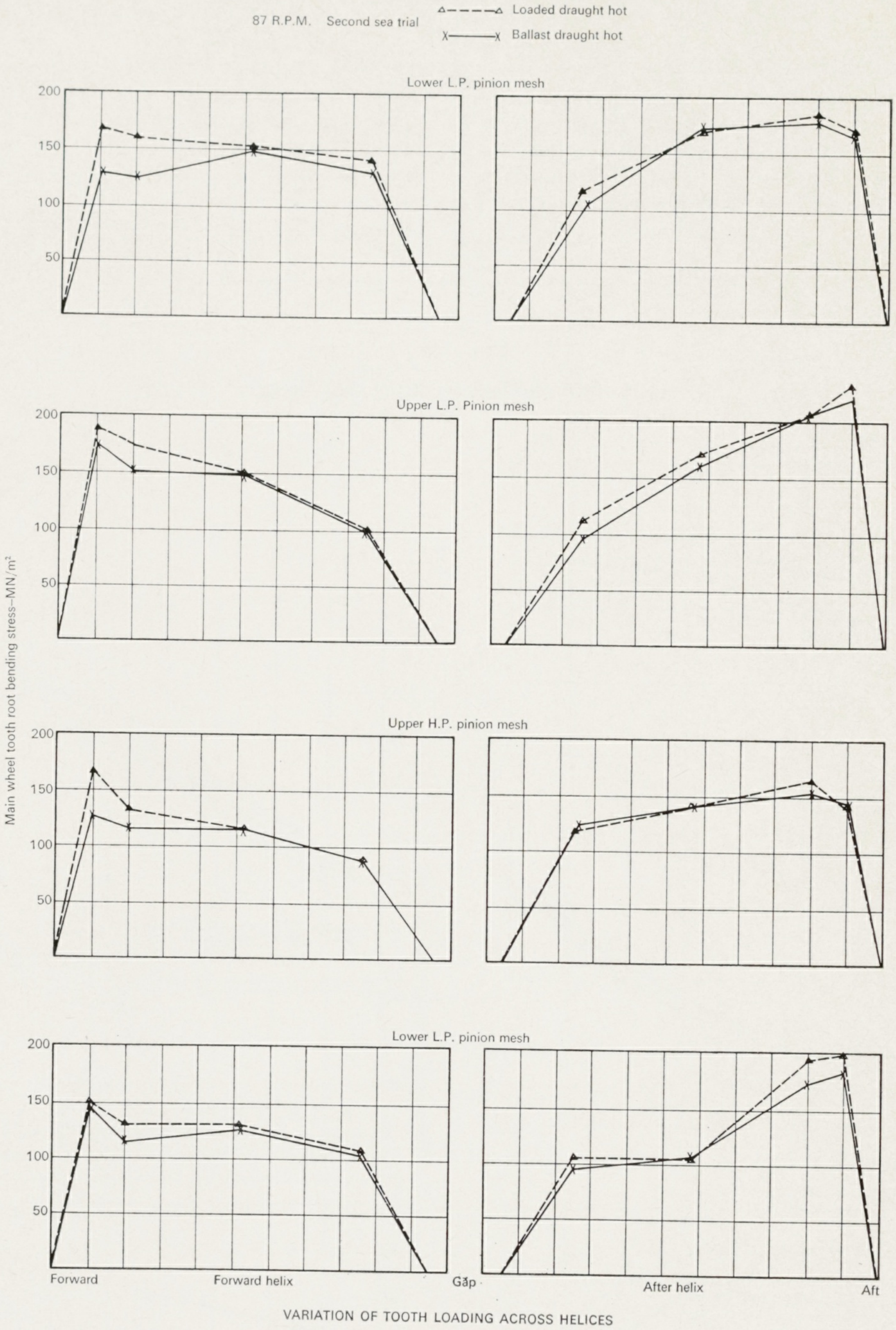

FIG. 7.1
Variation of tooth loading across helices.

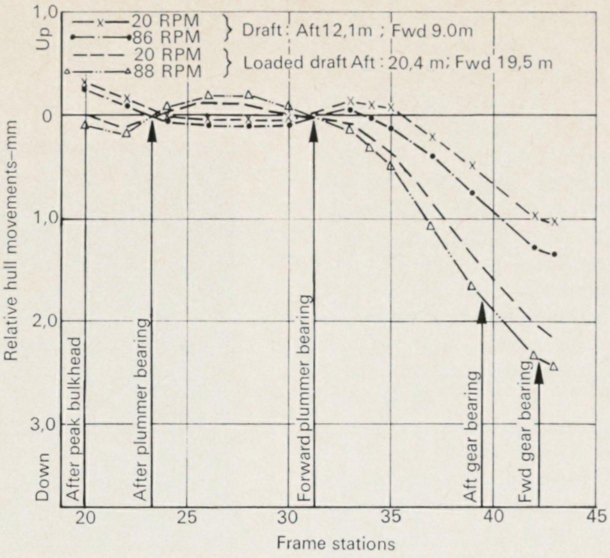

FIG. 7.2

Relative hull movements along shaft length.

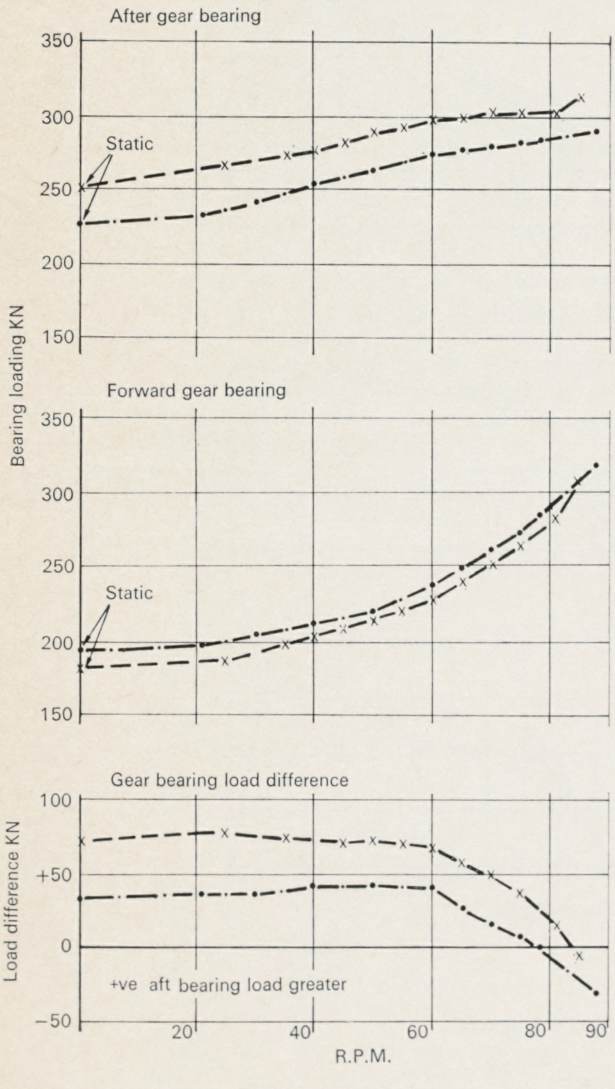

FIG. 7.3

Variation of main wheel journal bearing loading with shaft speed.

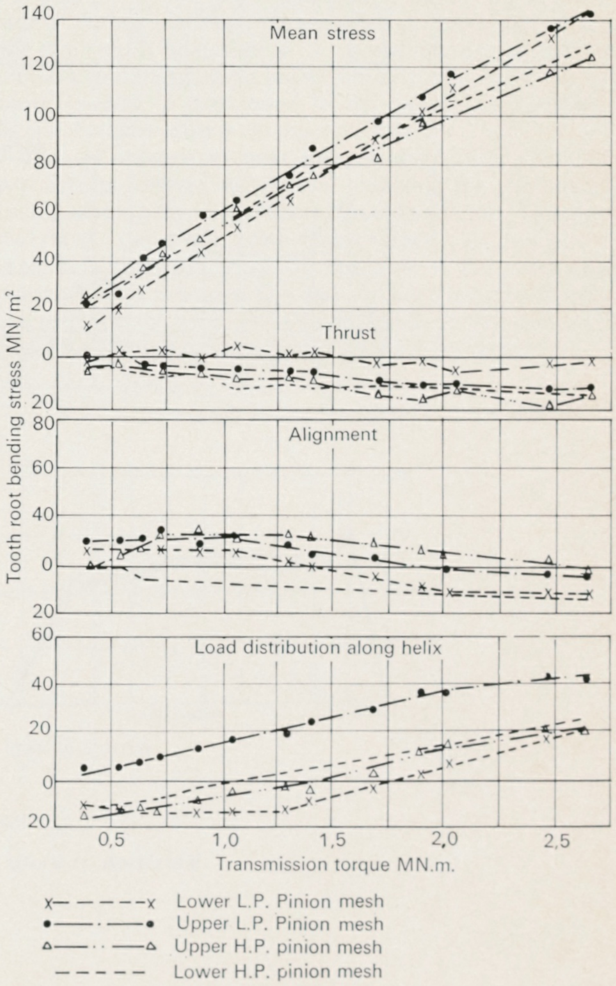

FIG. 7.4

Components of tooth load.

8 CONCLUDING REMARKS

The vast majority of the Surveyors in the Society have not had the opportunity to be directly involved in the work of the Department and it is hoped that this paper has been of interest to them.

The advances in measurement and analysis techniques have greatly increased the depth to which investigation and research work can be carried out. Indeed, the modern complex installations require that we utilize all the methods available.

The attachment to a shaft of a small black box which can transmit signals to a stationary receiver has resulted in major achievements in the measurement of gear teeth, propeller and crankshaft stresses. There is no doubt that, in the future, all electronic instrumentation, whether it be an amplifier or a computer, will decrease in size and increase in power and flexibility. Further, it is suggested that the rate of change is increasing and the improvements seen over the last few years in instrumentation and computing power will be dwarfed by the anticipated future developments.

In saying this, one must never lose sight of the fact that these methods are tools and are only as effective as the Engineer, Mathematician or Metallurgist using them.

Human experience, knowledge and skill can be augmented but never replaced.

ACKNOWLEDGEMENTS

The information presented in this paper is the work of Surveyors in the department carried out in many cases in trying and onerous conditions. In its preparation I am grateful for assistance received from several members in the Department and in particular Mr A. M. Jones whose help was outstanding.

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Lloyd's Register Technical Association

Discussion

on

Mr. D. McKinlay's Paper

THE SOLUTION OF ENGINEERING PROBLEMS BY FIELD MEASUREMENT AND ANALYTICAL STUDY

Paper No. 2. Session 1978-79

Hon. Sec. D. T. Boltwood
71 Fenchurch Street, London, EC3M 4BS

Discussion on Mr. D. McKinlay's Paper

THE SOLUTION OF ENGINEERING PROBLEMS BY FIELD MEASUREMENT AND ANALYTICAL STUDY

CONTRIBUTIONS

From Mr. F. Kunz:

It is pleasing to hear the Head of M.D.A.P.A.D. speak so highly of T.I.D. and to see that the sequence of case history papers coming out of T.I.D. has had another useful instalment added.

Mr. McKinlay might like to expand his thoughts on the general levels of tooth strain due to gearing inaccuracies and external influences such as torsion, misalignment or hull movements. We have come across examples of all of these contributing to gearing troubles over the last four years. To my own intense gratification there were even two cases where there was nothing whatsoever wrong with the gears or propulsion system. The Owners had suffered on previous vessels and wanted reassurance on newbuildings.

At the other end of the scale, tooth bending stresses were once measured on a locked train gear where one pinion was so badly out of phase that it took no load up to almost half torque. The Surveyor attending identified this from the tooth strain measurements and persuaded the Owners to put into the next port where the error was confirmed with normal engineering checks, and put right. It is unlikely that inspection of hard lacquer on trials would have shown this fault as the vessel had to complete a river passage before trials.

I fully concur with Mr. McKinlay that measurements are only tools and as good as the people using them. This places a heavy responsibility on us to use the new techniques wisely and with integrity. It is not necessarily in a Client's interest to use a sledge hammer to crack every nut, so less elaborate investigations retain their place.

In fact, behind every application of a new measuring technique used to investigate problems there has been a great effort to understand fully the meaning of the measurements. For example, at present we are taking an increasing number of machinery vibration signals as part of condition monitoring of rotating machinery. Some components of these signals, in particular the imbalance which is generally of prime interest, are relatively easy to comprehend and calibrate. But others are much more difficult to identify and classify, and require a lot of thought. Epicyclic gears could be taken as an example of this. All the normal manufacturing tolerances in such gears can give rise to vibratory signals at bearings and it is by no means simple to decide what is excessive without the benefit of considerable experience of the machine.

Mr. McKinlay has contributed much to the work of T.I.D., but in a way his most enduring contribution to our work must be to have combined the Propulsion Section and Advanced Engineering Services together with Technical Investigations on one floor, and to have pushed us further along the road to new and ever more difficult things.

Within the recent past we have had members of the Propulsion and Advanced Engineering Sections on field investigations, while T.I.D. Surveyors have carried out theoretical work in great depth on subjects not connected with current field investigations. This sort of overlap can give rise to problems but in my view is bound to enhance the effectiveness of R.A.T.A.S. in particular, and the Society in general.

From Dr. D. Sepahy:

I found this paper interesting, as it covers a wide spectrum of engineering problems, especially its analytical approach which is supported by experimental work.

Mr. McKinlay rightly showed concern about the cost of finite element analysis (NASTRAN), and I am sure that a great number of NASTRAN users, particularly newcomers, share his concern. Therefore, I will try to explain some causes of this apparent high cost. In my experience of the development of finite element systems and their application, I can confidently say that the finite element approach not only provides a reliable tool for the analyst to handle a wide range of simple and complex problems, but also if used skilfully, it is economical and cost effective. The excessive cost of analysis can be a symptom of one, or all, of the following:

a) Lack of familiarity with the finite system.

b) Lack of systematic approach to data preparation.

c) Lack of suitable data generation programs.

d) Inefficient use of the computer or use of expensive hardware.

e) Lack of an effective means to process massive computer output.

Of the above difficulties a) and b) can be overcome by adequate training and further experience with the system. Items c) and e) can be effectively tackled by the design and development of suitable data generation and post-process programs of a simple but general nature, since specialised programs are not cost effective for a large variety of work. Item d) can be resolved by further training or the use of specialists in the area. Furthermore, with future advances in computer technology and a reduction in computer hardware costs, it is expected that a dramatic reduction in the computer cost of finite element analysis will be seen.

An alternative approach is to carry out finite element analysis with the close co-operation and assistance of a finite element group, which could be organised to provide services for finite element users.

I would like to ask the author if he has any future plans to apply finite element techniques (e.g. NASTRAN) to more complex problems such as a non-linear analysis, e.g. non-linear coupling or fracture mechanics, etc., as dealt with in this paper. As an experienced user of finite element in a wide range of engineering problems, how would he advise new finite element users; should they build up their own specialist finite element and computer expertise or should they call upon an experienced finite element group?

From Mr. J. S. Carlton:

The production of a paper of the type that Mr. McKinlay has presented here tonight, represents a monumental achievement in compressing a vast amount of information on the very wide range of activities undertaken by the Technical Investigation and Advanced Engineering Department into the relatively limited space permitted by a technical paper.

It is, therefore, perhaps not entirely inappropriate for a discussion of this paper to briefly expand on a couple of

the topics which Mr. McKinlay has of necessity mentioned only in passing.

Such an instance is the Department's capability in using numerical analysis methods, and in particular, finite element analysis for the solution of pressure vessel and other engineering structural problems. Fig. 6.1 of the paper gives some idea of the complexities involved when the structure such as a gas storage tank can be satisfactorily modelled using simple plate elements.

However, when it is vital to pin-point the locations and magnitudes of extremely localised and critical stresses, the complexity of the mathematical model must significantly increase. One example of this type of investigation in which the Department recently became heavily involved is shown in Fig. A. The mathematical model outlined in this figure is of a welded undersea pipeline connection, comprising some 536 separate 20-node isoparametric elements arranged in a double layer about the surface of the pipeline connection so as to obtain the stress distribution through the wall of the structure at various locations including the weld connections. These circumferential weld connections, of which there were four in number, were the subject of special attention as typified by Fig. B so as to obtain a completely isoparametric representation of the structure, thereby eliminating problems of model degeneration. The mathematical model was then subjected to a variety of loading conditions including various combinations of internal pressure, axial loading and bending moment in order to study the stress distributions in the critical regions.

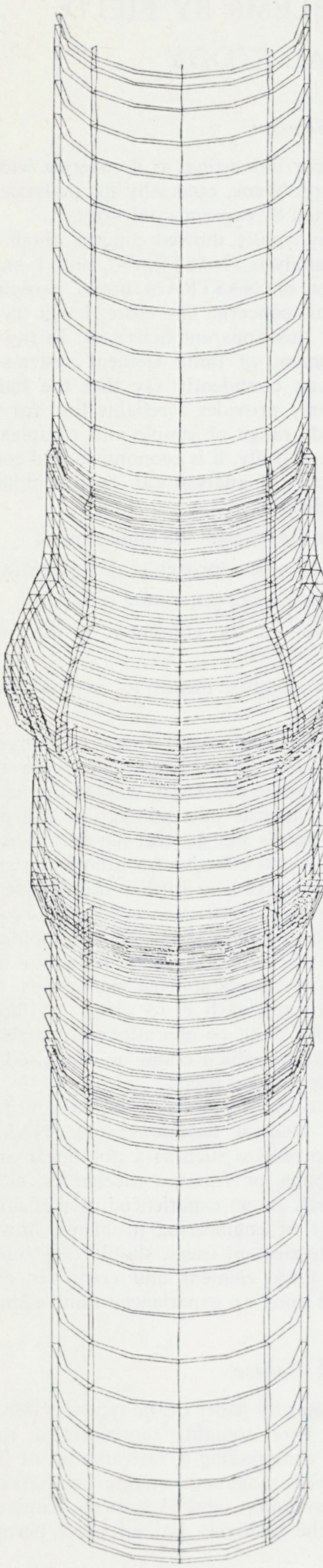

FIG. A

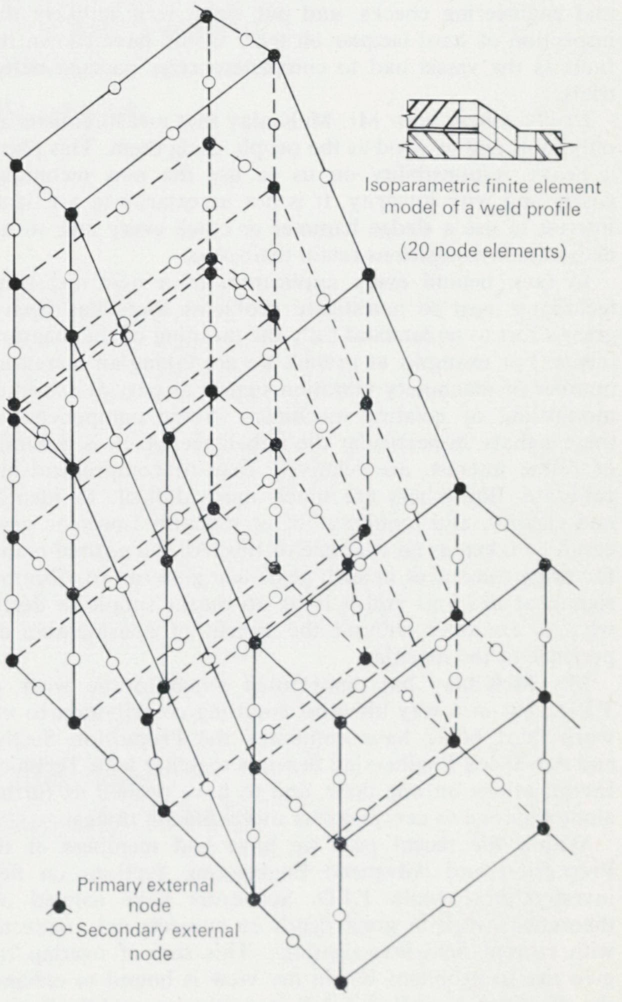

FIG. B

Fig. C shows an example of the detailed stress distributions obtained when the structure was subjected to an axial compressive load of about 800 tonnes, the contours of iso-stress being obtained from the computer output using mathematically based fairing techniques.

The degree of refinement regarding the magnitude and location of the stresses which can be provided by models of this type is well illustrated by Fig. C, however, it should be added that although in this instance the assumption of a linear elastic behaviour was adequate, the analysis is by no means limited in this regard, and an elastic-plastic analysis undertaken on a piecewise linear basis would obviously have been equally practicable, as in fact, would a solution which also involved thermal stresses due to a prescribed temperature distribution.

Naturally, the extensive application of finite element methods such as these can prove costly but can nevertheless, be justified in certain circumstances. However, in an attempt to keep costs to a minimum, maximum use can be made of any symmetry of both geometry and loading

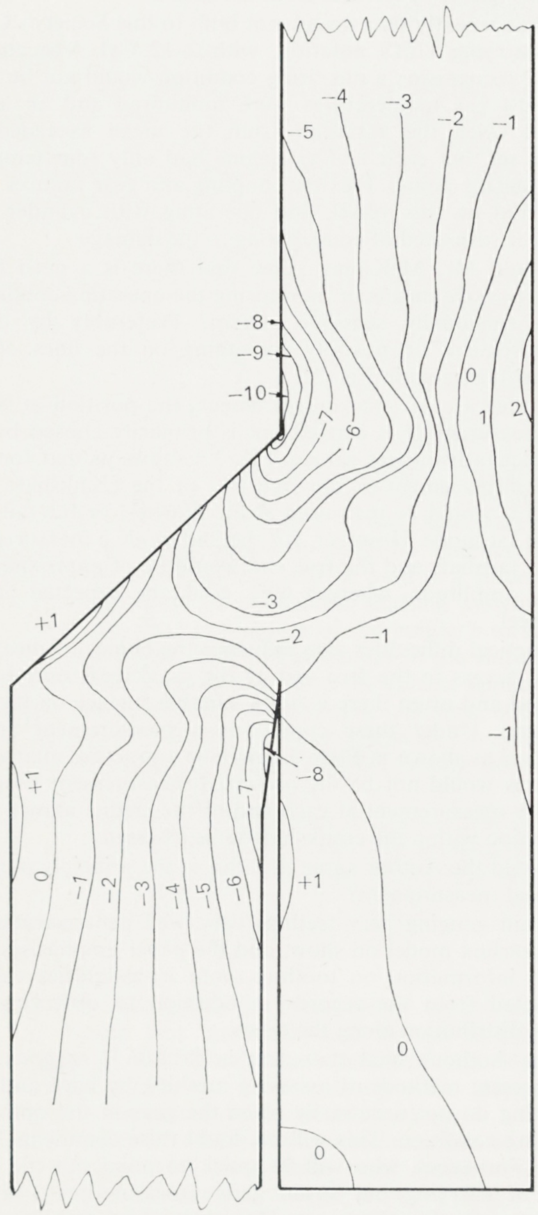

Fig. C

in addition to using finite element methods in association with other more classical procedures wherever possible, thereby, providing a useful and economic problem solving tool.

If we might now leave the consideration of the mechanical analysis of engineering structures and briefly look at the naval architectural section of Mr. McKinlay's paper, and in particular consider the implications arising from Fig. 5.6, which shows the improvement in vibration spectrum achieved by the fitting of a flow correcting fin to an L.P.G. carrier.

Flow correcting fins of the type shown in Fig. 5.4 (a) are becoming far more wide spread in their application to both existing ships and also new buildings than has hitherto been the case, and whilst if applied advisedly, they can reduce the vibration levels encountered in the vessel to an acceptable level, serious consideration must be given to both the hydrodynamic and the structural design of these types of appendage.

The considerations of fin strength are typified by Fig. D, which shows a comparison of the vibration spectrum of the orignial fin for the vessel mentioned in the paper, which resulted in considerable structural fatigue during the initial

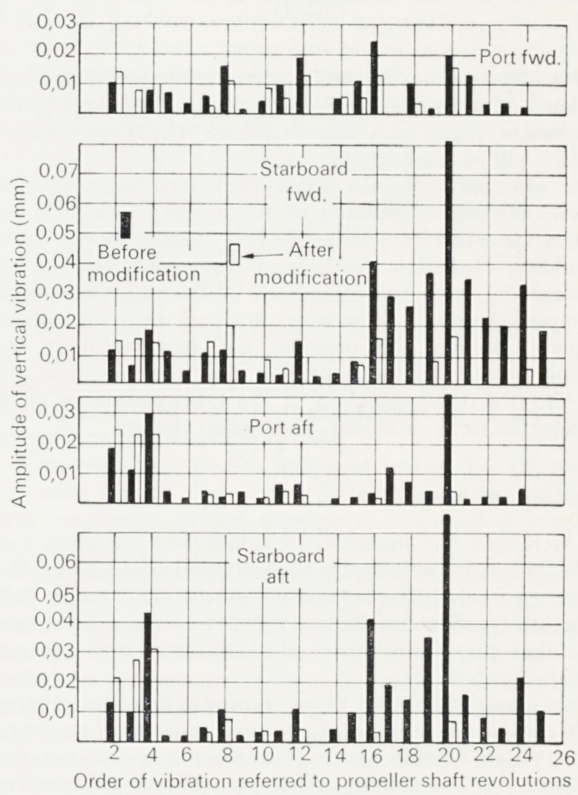

Fig. I

12 months service period, against the modified structural design which is in existence today. Generally, wake modifying fins present the partially conflicting requirements of providing adequate structural strength and rigidity whilst minimising the effects of added hydrodynamic resistance to the hull.

Considerations such as these lead the hydrodynamic investigator into searching for other ways to improve the vibrational characteristics of ships such as the new air cushioning techniques, or modifications to the propeller geometry in terms of radial pitch and skew distribution. Methods of this latter type can, if the right conditions prevail, prove just as effective in vibration suppression as

wake modification fins. For example Fig. E shows the change in vibration spectrum due to a change in the radial pitch distribution alone. The comparison between this spectrum and that shown in Fig. 5.6 of the paper is all the more interesting since they both relate to two sister ships where we had the opportunity to investigate the effects of both methods of vibration reduction concurrently.

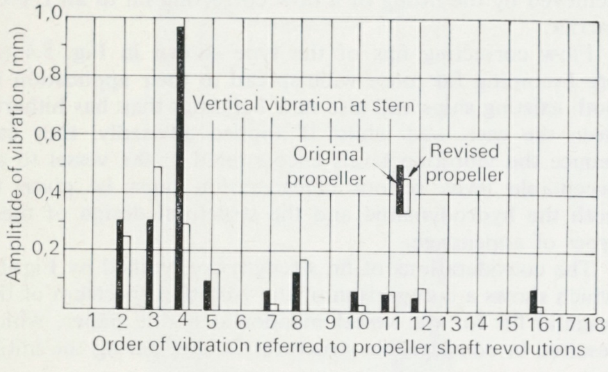

FIG. E

Naturally, techniques such as these relate to "in-service" problems. However, there is much that can be done in the early design stages of a ship to ensure that these types of measure will be unnecessary.

For example, one can apply the many heuristic and pseudo-analytical techniques of wake and hull profile assessment, in order to obtain the best possible design prior to building. However, this type of study must be done on an integrated basis considering all of the ship and engine parameters involved, otherwise one runs into the danger of merely solving one problem, e.g. hull vibration, but creating another in terms of, say, shafting vibration, the nett result at the completion of the investigation or study still being an irate, or at best, disgruntled Owner.

From Mr. R. Moore:

Mr. McKinlay has succeeded in condensing six aspects of the Technical Investigation and Advanced Engineering Department's work into a concise document of 15 pages. Sufficient information has been presented to show the broad scope that the Department's measurements and analysis techniques can cover.

Some investigations are planned months in advance, some materialise in a few hours. Some are requests for measurement for classification approval, and some are requests for assistance in overcoming recurring failures of stressed components, or to reduce vibration of living and working spaces to acceptable levels.

The samples Mr. McKinlay has included cover each of these three areas; but how is it decided what should be measured, and at which location should the measurement be taken?

In the case of torsional vibration measurements reference is made to the relevant calculations. Strain gauge measurements on the intermediate shaft and the crankshaft would be proposed for verification of the respective modes of vibration. A torsional swing measurement at the free end of the crankshaft may be used.

The strain gauging of a shaft forms the basis of much of the Department's work and the standard telemetry equipment can be adapted to cope with the diameters and shaft speeds normally encountered.

Where failures have occurred in specific components such as flexible couplings then the swing measurement illustrated in Fig. 2.1 can provide much information on the dynamic behaviour of the coupling.

Whether the technique employs the potentionmeter, as illustrated, or the strain gauge beam, as mentioned in the text, the device provides a simple and direct measurement. The measurement arm is offset in the static condition such that as angular twist of the flexible element occurs, during the application of transmission torque, the arm moves through the offset to the mid-position. In this way the linearity of the measurement is maintained.

Our torsional vibration reports on medium speed installations often conclude with a recommendation that in the event of cylinder, or cylinders mis-firing the engine should not be operated within certain speed ranges. Restrictions of this type are also made in classification approval of some systems. This depends on the operating engineer recognising the mis-firing condition and any automatic warning is normally given by monitoring the variation of one or more exhaust gas temperatures from the mean.

I was recently on a vessel, not built to this Society's Class, but carrying UMS notation, with 2–12 Cyl. Vee engines where recognising a mis-firing condition would not be easy. Exhaust gas temperatures were monitored and an alarm raised when the variation from the mean exceeded the limits set, but each 12 Cyl. engine had only four temperature sensing points. Flexible coupling and gear failures have occurred on this vessel, and operating with cylinder mis-firing is suspected of contributing to the damage.

Would Mr. McKinlay agree that there is a need for a more positive means of monitoring the operating conditions of a torsionally sensitive system? Preferably by direct measurement, or possibly something on the lines of the device illustrated in Fig. 2?

In the case of axial measurements the position at which the measurement is carried out is primarily chosen by the technical advantages gained. Fig. 3.3 shows us that for unit axial displacement at the free end of the crankshaft only 30–35% would be measured at the flywheel or the tailshaft in the 1st mode. However, for the 2nd mode a measurement at the tailshaft and the free end would be of approximately equal amplitude, whereas 60% could be expected at the flywheel.

Practical difficulties also influence the choice of measurement, access to the free end of the crankshaft may be restricted and often there is not a suitable surface on the line shafting. Under these conditions a measurement at the flywheel as shown in Plate 3.2 may be a practical alternative but this would not be the preferred measurement position. Ideally measurement at each end of the engine allows axial deflection within the crankshaft to be assessed.

Would the Author agree that this is the principle purpose of axial measurement?

Strain gauging gear teeth is very well demonstrated by the gearbox model on show, and the paper emphasises that much information on tooth-to-tooth irregularaties can be extracted from the records in addition to observing the stress distribution along the tooth.

The Author's final statement in Section 7 suggests that the present methods of assessing meshing by hard and soft marking do not necessarily place the gear in the optimum running condition. This will no doubt raise comments from some Surveyors, who will be quick to point out the high cost of carrying out strain gauge measurements of the type described in the paper. However, where troubles have been experienced, Shipbuilders, Gear Manufacturers and Shipowners have appreciated the importance of the results to the extent that much of the sea trial on a recent large

steam installation was allocated to measurement and subsequent adjustment of the pinions.

The Author's concluding remarks that few of the Society's Surveyors have had the opportunity to be directly involved in the work of the Department are certainly true. By the nature of the work, i.e. "Field Measurement", we find ourselves in many of the outports, and in this respect we are grateful for the assistance which is often given by the local Surveyors.

From Mr. A. C. Wordsworth:

This paper impressively demonstrates the wide range of investigations which can be undertaken by T.I. and A.E.S. Department.

A point which I would like to raise is the suggestion in the concluding remarks that the improvements in instrumentation over the last few years will be dwarfed by future developments. It is now possible to measure reliably stresses, displacements and temperatures on rotating and oscillating machinery in the most hostile environments, thus satisfying measurement requirements which, as Mr. McClimont has said, were obvious fifteen years ago but impossible to achieve. It seems to me that there are no longer similarly obvious and unresolved requirements whose eventual attainment will equal, let alone dwarf, those now satisfied.

The recent impressive developments in instrumentation have largely been as a result of "spin off" from the American Space Programme and I would suggest that developments on this scale will only occur under the spur of either war, or a research programme of the magnitude of the space programme.

Could Mr. McKinlay indicate in what areas he expects to see instrumentation develop and who will provide the necessary finance?

WRITTEN CONTRIBUTIONS

From Mr. B. P. Cosson:

I have read Mr. McKinlay's paper with interest and the remarks I am about to make are not intended as criticism, but more as observations on a few points which, to my mind, need further clarification. It is a pity that some of the photographs did not reproduce well, as I suspect the Author shares my belief that a well chosen picture can be more informative than a thousand words.

With regard to the failed flexible coupling it is stated that the prime cause of failure was due to overload. Could the Author be more specific and comment whether this overload was solely of a cyclic nature, as the elongated bolt holes suggest possible transitory shock loading and inadequate security of assembly as contributory factors. It is not clear why a larger coupling having presumably a much greater load capacity should also fail, under, what appears to be from graph 2.4., not very arduous vibratory conditions.

Of greater potential significance is Mr. McKinlay's assertion that in some instances dynamic characteristics specified for the couplings can only be used as a guide. The classification approval of propulsion shafting systems involves, inter alia, the examination of the builder's torsional vibration calculations prior to installation in the ships. The majority of these analyses rely upon the correct application of flexible coupling data, in particular dynamic stiffness. Would he care to elucidate in which instances the coupling manufacturer's published characteristics cannot be relied upon?

It would also be very interesting to learn if the manufacturer of the tyre coupling which failed accepted responsibility for supplying a coupling which was 300 per cent stiffer than specified, as this would seem to be a gross contravention of the Trade Description Act!!

Mr. P. F. Horne:

Mr. McKinlay has given, by examples of some types of work, an insight into the work done by the R.A.T.A.S. Departments of T.I.D./Propulsion Section/A.E.S. He has indicated that calculations are frequently made using purpose written software of a finite element package.

Mention might be made of the increasing use of interactive programs which have either been written for the computer section of the Data Logger shown in Fig. 6.2 of the paper or, more recently, using A.P.L. One approach has been to modify a program for the IBM370 to store results of a calculation so that these may be accessed by A.P.L. to perform optimisation calculations interactively, having first done the major part of the "number crunching" in the most economical manner. This has involved co-operation between those involved in software development, the handling of system files by A.P.L. and those developing A.P.L. functions for use in the department.

Such interactive routines are of particular value when optimisation of a number of possibly conflicting requirements is required as in the alignment of shafting systems.

Mr. B. Wilson:

I would like to add my thanks to Mr. McKinlay on both the presentation and delivery of his paper, and would ask if he could confirm or otherwise that the "dots" (in Fig. 2.1) indicating the "Rubber" should also be shown outside the position of the clamping bolts.

With regard to the fins indicated in Fig. 5.4. On several occasions fins of these types have failed structurally and have sometimes caused damage to the shell structure in their proximity.

Since these fins are usually fitted as remedial measures after the completion of the ship, and their contours are usually dictated by the experimental establishments, it is generally very difficult for the structural designer and constructor to produce fins (with associated ship internal structure) to the standards to which they are normally accustomed. In fact, they generally stand little or no chance to produce structural arrangements which they consider to be satisfactory. This being due to the lack of internal access for welding and to the completion of pipework, etc. in the engine room (since the engine room usually lies inboard of the fins).

The structural designer is usually the last person to be involved and his comments are seldom sought until after the fins' form has been finalised.

With regard to the idealised mathematical model shown in Fig. 6.1, I trust that this illustration was produced at the data checking stage of the analysis, since it would appear that several elements have been incorrectly specified.

It is a pity that Mr. McKinlay did not request heavier type for the last sentence in his concluding remarks, since I am sure, we all can be overawed, at times, by the "tools".

AUTHOR'S REPLY

Initially I would like to take this opportunity of thanking those colleagues who have contributed to the discussion.

To Mr. F. Kunz:

Mr. Kunz's experience in gear tooth measurements is unrivalled at this time in the Society and he has made a large personal contribution to the developments of the technique.

I feel that we have not yet fully exploited this method and I look forward to the next phase of development. We have seen the effects of mis-alignment, torsional vibration and pitch errors on tooth strain measurement, however there could be other effects which can only be resolved with instrumentation of very high frequency response. I would hope that Mr. Kunz's department will be able to look at this and establish if such instrumentation can be used effectively.

To Dr. D. Sepahy:

I am grateful for Dr. Sepahy's explanation of how the cost of finite element analysis can be reduced. We must expect that as costs come down the utilization of the system will be greater. It may be that we will use finite element techniques on the non-linear problems mentioned in the paper. The subject of couplings will be examined in detail, and naturally we will tackle it with the best methods available.

It is my opinion that individual departments should be capable of using the tools they require and in the case of finite element work an expert group, such as Dr. Sepahy's, is essential to assist when problems are experienced and to introduce the necessary advances in technique.

To Mr. J. S. Carlton:

I am grateful for Mr. Carlton's contribution which goes into detail of some of the work he has undertaken. His contribution has certainly increased the value of the paper.

To Mr. R. Moore:

We have seen the problems mentioned by Mr. Moore several times that, with the engine mis-firing, coupling damage can take place. I agree there is a need for a monitoring instrument, preferably fitted to the coupling or shafting close to the coupling. I would not think, however, that the device illustrated in Fig. 2 was the ideal instrument for long term operation.

In trying to answer the questions raised by Mr. Moore on axial measurement, I would say that it is usually desirable to take measurements where the phenomenom being assessed has its largest effect, irrespective of whether the phenomenom is strain, acceleration, or linear motion. However, the positions where we can measure in practice are usually limited and therefore we have to compromise. In the case of vibration measurement to establish the mode shape, it is necessary to measure the system at different positions with instrumentation which is capable of comparing phase as well as magnitude. If the effects on crankshaft of axial vibration are being investigated then measurements at both ends of the shaft are useful. It is possible, however, that a more meaningful measurement would be achieved with strain gauges in the fillets of the crankshaft and, with modern instrumentation, this can be done without modifying the engine.

To Mr. A. C. Wordsworth:

I must agree with Mr. Wordsworth that many developments have come from the "spin-off" from military or space contracts, but I do not believe that these are the only spurs. For example, we are now seeing governments financing large commercial research and production programmes, the spur being international or even intercontinental competition. The United Kingdom's government is now committed to spend large sums of tax payers' money to fund the use of production development of the micro-processor.

Mr. Wordsworth has asked me to gaze into the crystal ball and come up with answers on how instrumentation will develop. I know what an experienced man Mr. Wordsworth is, and suggest that he be guided by history and his own experience for an answer. Look at the improvements we have seen in these instruments over the last 20 years, e.g. increase in power, reduction in size, continuous improvement in ability to operate in an hostile environment, improvement in speed and accuracy of analysis. I do not believe that there is any reason why these developments should not continue at possibly an even greater pace than before.

To Mr. B. P. Cosson:

Mr. Cosson's comments on the torsional vibration aspects of the paper are useful in that they highlight some of the problems of the Department with which he is associated.

The first question he asked was what was the nature of the overload of the coupling which failed. It must be accepted that unless shock loadings are repeated frequently it is unlikely that they will be seen when measurements are taken, therefore, an area of doubt can exist. In this case however, I believe that the operational experience of the vessel, together with the nature of the damage and the results of the measurements, indicated that the overload was of a cyclic nature.

I hope that in the not too distant future the Society will have detailed answers to the questions he asked on dynamic stiffness. The paper quotes two different makes of coupling where problems were experienced, and this must lead to caution when dealing with other types of coupling using the mathematical tools we have available at this time.

To Mr. P. F. Horne:

In reply to Mr. Horne I must admit that there are many other points which could have been drawn out in the paper, and he is quite right to mention the advances being made in numerical techniques. He also indicates the amount of inter-departmental co-operation and work required to make these techniques successful, and we are always grateful for any help we receive from different departments and individuals in the Society.

To Mr. B. Wilson:

Mr. Wilson is quite correct that there should be "dots" outside the clamping bolts for the Fig. 1 and I am grateful to him for pointing out this omission.

The mathematical model illustrated was not the model used in the final analysis. This diagram was presented to illustrate the complex nature of the analysis now undertaken. Mr. Carlton's contribution in this respect gives further indication of what I was trying to achieve with my selection.

AUTHOR'S FOOTNOTE

It has been brought to the Author's attention that an error exists in page 12 of the paper. In the third paragraph from the end 0.1 mm should read 0.01 mm.

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A. Bell (6)

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INSULATION AND RELATED TECHNIQUES APPLIED TO TEMPERATURE/PRESSURE CONTROL FOR LIQUEFIED GAS AND CHEMICAL CONTAINMENT SYSTEMS

M. Z. Navaz

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INSULATION AND RELATED TECHNIQUES APPLIED TO TEMPERATURE/PRESSURE CONTROL FOR LIQUEFIED GAS AND CHEMICAL CONTAINMENT SYSTEMS

By M. Z. NAVAZ

INTRODUCTION

Among scientists, the low temperature field refers to the cryogenic part of the temperature scale below minus 150°C (123K). Some countries have preferred to choose a temperature of minus 100°C (173K) as the upper demarcation temperature limit. In the commercial world much higher temperatures have been selected to specify the upper limits of the low temperature field of engineering associated with insulation work. For this paper 0°C (273K) has been used as the upper limiting temperature of the low temperature field.

The paper attempts to discuss present day thinking among regulatory bodies concerned with inspection, quality control, design evaluation, safety matters, testing and periodic inspection associated with the installation of insulation systems in the low temperature field.

Heat leakage takes place from one adjoining environment into another when there is a temperature difference between the two until conditions of equilibrium are reached. To maintain a design low temperature environment, thermal isolation has to be provided and this is achieved by insulating the environment. Insulating materials do not stop heat flow, they merely retard rates of heat leakage. By the judicious application of a heat pump, the small amounts of heat flow into the low temperature environment may be removed to maintain it at its required temperature. The effect of insulation on the rate of heat flow is a function of its properties and the design of the insulation arrangement.

In 1892, Sir James Dewar designed the internally-silvered double walled glass envelope container, the annular space between the walls being permanently evacuated. This still remains the greatest single advance made in the subject of thermal insulation, and to honour this event such vessels are usually described as 'Dewars'. Dewars exceeding 10^{-3} m^3 capacity are normally made of metal, whereas for smaller volumes, glass construction is employed. Pyrex is used on account of its ability to withstand thermal shocks, however, Monax glass is preferred for liquid helium.

Low temperature environments are used for food preservation, for condensation techniques in the chemical and petrochemical field, for the manufacture of liquefied gas, etc., and in relation to aeronautics and inter-planetary vehicle engineering, the storage of refrigerated liquefied gas, etc. However, the following three main factors make highly efficient insulation essential for low temperature engineering.

1. The cost of refrigeration increases rapidly as the temperature falls.
2. Most liquids require a decreasing amount of heat to evaporate a unit volume at low temperature whether the liquid is in storage or used as a refrigerant.
3. Heat leakage into a low temperature environment increases greater than in a linear manner as the temperature difference with the outside ambient increases.

It is, therefore, important to consider the design of the insulation system in the early stages of the design of the containment system and not as an after-thought where it is merely applied as an external cladding. The engineering of the insulation system must not only consider heat leakage problems, but it must be designed to play a complementary role in protecting life and property.

INSULATING MATERIALS

The term insulation is often used in technical literature as a noun referring to material or media, and as a verb inferring a process that results in establishing the media of insulation around a containment system. The simplified meaning of the word insulation is isolation, but although the aim is to prevent heat transfer, in practice, insulating materials will only retard or reduce heat flow. In engineering, insulation techniques in association with appropriate materials may also be used to control noise levels, electrical potential levels, etc. This paper attempts to examine insulation aspects for the containment of liquefied gases and chemicals which require pressure/temperature control within strict design and operating limits. These parameters are two of the most important associated with safe containment. The part played by insulation materials and the technique of insulation are considered in the manner in which they help to control heat flow and in turn these two main parameters. In effect, the control of the temperature of liquefied gases and chemical cargoes is the vital factor, and especially when storage is at sub-zero temperatures.

All materials, irrespective of whether in the solid, liquid or vapour state, offer some resistance to heat transfer. Some are good insulators by virtue of the fact that they offer high resistance to heat transfer, whilst others are poor insulators with little resistance. Generally, a material offers its maximum resistance to heat flow under static conditions, when it is in the vapour state, less in the liquid state and less again in the solid state. Should movement take place within the vapour, liquid or solid then the resistance to heat transfer is likely to alter.

The degree of technology associated with an insulation system depends upon the function it is called upon to fulfil. This varies from the simple, represented by external cladding around the containment, to the more complex, associated with internal insulation. In the latter case the insulation may act as part of the containment system.

There are a variety of materials that could be used as insulants. They may be naturally grown or manufactured and be in the form of powder, prefoamed blocks, foamed in-situ, fibrous or composite materials. In Appendix 'A' some typical methods of locating insulation systems are shown and in Appendix 'B' some of the insulation materials are detailed. The use of vacuum walled tanks, with or without powder or composite insulation, has been used extensively as containers for the carriage of cryogenic cargoes. Container vessels up to 40 tons capacity have been used on shipboard service.

In recent years fabricated composite insulation materials have been used in place of vacuum walled containers for very large cryogenic storage systems. A prefoamed organic foam such as polyurethane, used with or without foamed in-situ insulation within a woodwork matrix, is a common form of insulation system for liquefied gas containers, while in some instances a powder insulation is used. The straightforward foamed in-situ, prefoamed block, or fibrous materials are often used for containment purposes down to minus 55°C with foamed glass and organic wool materials also being popular in this temperature range.

Foamed in-situ and prefoamed organic foams, together with powder insulation are used for temperatures below minus 55°C, while composite layers of balsa wood have been used as suitable insulation for fully refrigerated liquefied natural gas containment systems at minus 165°C.

With powder insulation systems subjected to extensive vibration, means should be provided to prevent extensive compacting of the insulation. This is done by either providing a gas circulation to keep the powder buoyant, by a wood honeycomb structure or by a combination of both, together with means of collecting the overspill and 'topping up' the insulation space periodically. In the gas circulation process, pressure differentials should be kept to a very minimum, otherwise it will adversely affect the overall thermal conductivity of the insulation. For marine application, it is normal to waterproof the powder insulation by the addition of chemicals.

With foamed in-situ organic foams, exothermic in character, care is required during foaming to ensure that the surface temperatures are controlled to establish designed cell growth and density. Care should also be taken to prevent the growth of fissures, cracks and voids within the foam. In order to prevent low temperature fatigue cracks within the insulation, it is normal to insulate in thin layers, thus providing a crack arrester between each layer. Some of the crack arresters may take the form of an open mesh material. To control the quality of the insulating material within specification requirements when foaming in-situ, the foaming arrangements should be such that coupon pieces are available which are surplus to the insulation system and are representative of the foam. These coupon pieces enable quality control to be maintained by visual examination and suitable testing procedures. (*See* Appendix 'C' and 'D'.)

The internally situated insulation system in contact with the dry or wet environment has been used extensively. With shore tanks and refrigerated ships, the insulation may be lined with a waterproof protective coating or sheathed with wood, and for liquid containment purposes it may be covered with a metallic lining or a mastic compound or left exposed to the liquid and gaseous phase of the cargo, in which case the insulation is a closed cell type. There is also the possibility of using open cell internally lined insulation, where the liquid seal is obtained within the insulation by the flashing of the liquid into vapour in the higher temperature regions within the insulation. This latter system, however, presents problems with liquid drainage and gas freeing.

In the design of a primary container, where fracture mechanics is a discipline used in the evaluation of the structural scantlings, the insulation system requires to be arranged in such a manner so as to detect leaks when cracks occur right through the parent plate. This is done by arranging a leakage trough within the insulation system at places where leakage is likely to occur due to high stress concentration, weld areas, points of attachment, etc. The trough is filled with a soft porous insulation which would collect and lead liquid spillage to leakage sensing points. The object of the above design is to detect the through crack as early as possible so that corrective measures may be taken before the crack growth develops into large scale spillage.

Reinforced concrete structures have been used as containment systems for land based installations. Studies have also been made for its use as a shipbuilding material for liquefied gas containment systems—with its greater resistance to heat transfer as opposed to steel, the design presents an attractive proposition for internally insulated containment systems.

QUALITY CONTROL AND WORKMANSHIP

Insulation materials, whether for an external or internal system, must comply with the design requirements. Unless a very careful check is kept on the quality at all stages, from the initial supplier to the finished product, faults may be introduced that are detrimental to safety and reliability in service.

The material requirements should cover the following:

(a) The order, including the material specification placed on the raw material supplier.

(b) The dates associated with the order, manufacture and delivery.

(c) A random sampling technique for establishing the quality of the chemical when delivered—plus limiting dates for application set by the quality control chemist and marked in the containers.

(d) Method of despatching and conditions of storage at site.

(e) Stock control at site.

(f) Consumption at site together with methods of identification of pot contents with name of applicator and the geographical location of the in-situ application.

(g) The preparation of samples of the insulation system for destructive testing, and the techniques of non-destructive testing and standards of acceptance.

(h) The method of recording the foregoing and production stage data.

(i) Method by which the finished product is to be stored and preserved till all the work is completed.

It will be appreciated that the above quality control requirements will also depend on the technique of steel fabrication used by the shipbuilders. Thus these requirements may have to be modified to take account of the practice at the shipyard. The surveyor at the shipyard should make sure that the quality control conditions are observed or are modified to maintain a sound product. Sand blasting, plate cleaning, washing and painting are operations that define the foundation of the insulation system—environmental control during storage and application should not be overlooked.

The insulator's practical skill to do work according to specification must be examined and certified at least once in 3 months. The insulator must also be in a position to identify faults in the end product and be familiar with the quality control discipline that is to be established. More than two consecutive mechanical failures on check test pieces should automatically stop work until the fault is identified and rectified. Work should not proceed till tests on sample pieces are satisfactory in all respects. There should be at least two sample pieces for each pot of chemical used—one representative of the insulation at the start of insulation and the other at the end of insulation. From the foregoing it is seen that the material testing laboratory should be set up close at hand to the insulation area.

INTERNAL INSULATION SYSTEM

For over 12 years the Society has been studying designs of internal insulation systems. Vast sums of money are still being spent in many industrial countries throughout the world in developing suitable insulated surfaces to enable liquefied cryogenic cargoes to be stored and transported. The Society at present is involved with over eight internal insulation systems representing well over 50 research years of investigation. The world's first liquefied gas containment system with internal insulation, sailed the high seas for two years as an experimental liquefied gas tanker for temperatures down to minus 48°C. The Society in co-operation with the owners and designers maintained close observation on the data collected during its commercial voyages. Since then, ocean going purpose built ships have been constructed to the fundamental conception of the system used on the first experimental tank.

In 1975 IMCO published its Code for Liquefied Gas Ships with IACS having played a prominent part in the drafting of Chapters 4, 5 and 6, dealing with the cargo containment systems, process pressure vessels and materials of construction. The Code was drafted around cargo containment systems that were in existence around 1971 and onwards. Paragraph 4.4. defines general requirements for structural analysis while

paragraph 4.2.2. defines membrane tanks and conditions as follows:

4.2.2 **Membrane Tanks**

(a) Membrane tanks are non-self-supporting tanks which consist of a thin layer (membrane) supported through insulation by the adjacent hull structure. The membrane is designed in such a way that thermal and other expansion or contraction is compensated for without undue stressing of the membrane.

(b) The design vapour pressure, P_o should not normally exceed 0.25 kp/cm^2. If, however, the hull scantlings are increased accordingly, and consideration is given, where appropriate, to the strength of the supporting insulation, P_o may be increased to a higher value but less than 0.7 kp/cm^2.

(c) The definition of membrane tanks does not exclude designs such as those in which non-metallic membranes are used or in which membranes are included or incorporated in insulation. Such designs require, however, special consideration by the Administration.

The above was supposed to cater for such designs but some National Authorities refused to concede this fact. Much of this came to light in May/June 1977, when firm orders were placed for ships with internal insulation systems for certain long term charter between two trading ports.

Lloyd's Register and a number of National Authorities had already given full approval in principle for the containment systems in the light of the broad interpretation of the IMCO Code and the Society's Rules. In the light of requirements in other chapters on instrumentation, environmental control, etc., a few National Authorities questioned the compliance of the containment system with the Code and found it difficult to accept the 'equalivency' code requirement as a means of establishing the confidence level in the design. This led to the submission of amendments to the Code by a National Authority in order to clarify areas of ambiguity. IMCO asked IACS to examine the whole question of internal insulation as a primary barrier or a secondary barrier, and membrane faced insulation systems where the membrane acts as a liquid tight membrane. The net result of all this was that IACS reviewed the whole Code and decided as follows:

(a) Not to make any comments on membrane systems as they felt that these were adequately catered for in the Code.

(b) Proposed requirements for internal insulation systems related to the following:

Type 1 is an internal insulation system with or without liners, acting purely as a primary barrier supported by a load bearing structure.

Type 2 is an internal insulation system with or without liners, acting purely as a secondary barrier supported by a load bearing structure.

Type 3 is an internal insulation system with or without a liner, incorporating both the primary and secondary barriers of the containment system.

The IACS proposed amendments are to be discussed at IMCO by the end of 1978. These are likely to create problems because IMCO's original request for consideration of membrane containment systems was rejected by IACS. This is unfortunate. Some of the present containment systems which are being devloped as internal insulation systems, are likely to opt out as membrane containment systems simply because the existing requirements are less severe for such systems. Secondly, the 'liner' proposed for an internal insulation system is only there as a crack arrester in many designs. It is possible to make these liners liquid tight (and some designs do). In such a case an internal insulation system could easily be claimed as a membrane containment system and be the subject of less stringent requirements.

COMPUTER ANALYSIS OF INSULATION SYSTEMS

From the previous section it is seen that the designer of an insulation system requires data on the rate of heat flow into the container, and the temperature distribution. The former governs the type and thickness of the insulation, the degree of control over the pressure and temperature of the contents, the capacity of the reliquefaction plant, etc. The latter is important to considerations of thermal stresses particularly in the material of internal insulation.

The Society has developed computer techniques for effecting calculations relevant to the determination of such data. In general, it is relatively simple to make calculations for steady state conditions. Transient conditions considerably complicate the calculations. The input data is also difficult to define because variations stem from a number of sources and are of uncertain magnitude. For example, the ambient temperature is influenced by geographical location and varies over the day. The temperature on the outer surface of the containment system exposed to the atmosphere is further influenced by wind and moisture.

Problems also arise with heat transfer because of convection currents in the solid and void space media. The size of the storage container poses problems of variation within the tolerances on shape, thickness, fit up, surface condition and material properties. Another factor with a large volume of LNG or LPG is layering of liquid of different temperatures but within the upper and lower limits of design. The layering is caused by differences in density with temperature of the liquid gas. Major layering can promote roll over of the contents following a disturbance by mechanical movement of a mobile tank or by rapid convection.

The accuracy of calculations which neglect or approximate some of these effects can only be determined by measurements in service. Although some comparisons have been made between calculated and measured temperature distributions, much remains to be done to establish the level of confidence in calculated values.

The calculation of thermal stresses presents the most difficulty because an accurate knowledge of temperature transients is essential to the determination of peak stresses which govern failure by thermal fatigue.

In recent years, major advances have been made in the evaluation of the strength of constructional materials such as steels and aluminium alloys, in the presence of unavoidable manufacturing defect or a defect which develops in service. The fracture toughness of the parent materials and weld zones can be measured by experimental techniques, and these properties can be used in the calculation of the sizes of defects which will promote major rupture. Insulation materials have received little consideration. If these materials are to be used as an internal insulation system their defect tolerance must be further investigated.

HEAT PUMPS

The role of the heat pump in the low temperature containment system, as a complementary means of controlling heat flow, cannot be overlooked in this paper. Where heat pumps are provided, then the capacity and operational requirements must be intimately interlocked with the role the insulation systems provide for heat retardation purposes. Any discrepancy in either system impairs the overall object that has to be achieved by the low temperature containment system. In these days where penalties are written into constructional clauses regarding guaranteed heat leakage under predefined

conditions, measurement techniques should be agreed at the onset by all parties concerned, i.e. the insulating contractors and the plant manufacturers, etc. It is often the plant that is used to measure the heat flow rates, and it should be noted that there is still development work required in improving measurement techniques. It is also necessary to institute strict inspection and stage by stage testing and calibration. All this has to be done in a mutually agreed manner. The testing procedure itself must become a part of the design specification, i.e. of the measuring instrument and the discipline involved in measuring the heat leakage.

Boiling liquids may be used in place of heat pumps. Liquid nitrogen is often used to remove heat from low temperature containment systems. It is sometimes located between a pair of concentric Dewar jars to act as the insulating media and heat pump for the container. Liquid helium is shipped in this fashion in 800 litre containers on decks of cargo ships.

FREE SURFACE AREA INSULATION

In liquefied gas containers which have large free surface areas, insulation may be provided in order to reduce evaporation into the vapour void spaces due to radiation heat flow, mechanical heat generated due to sloshing in mobile containers, etc. One method is to use small plastic balls filled with inert gas and floating on the surface of the liquid. Two or three layers of floating balls may be provided to further reduce the evaporation losses. Since the balls float freely, they take up an orderly position within the tank on the free surface. Suction guards are provided to prevent the balls being drawn into the pump during discharge. When liquid filling commences, the balls once again take up their orderly floating position. There is no reason why other forms of insulation should not be used, such as inflated rafts or floating insulation filled mattresses. It must be pointed out that with flammable liquids, these insulation systems provide an added safety precaution to the free surface.

MOISTURE

Where temperature differences are established in an insulating media, entrapped vapour migration takes place according to the mannerism and the direction of heat flow and the established thermal buoyancy. The simple rule being that areas of low temperature would establish high vapour density areas and those of high temperature, low density areas. Relative to the vapour pressure and the temperature established, buoyant vapours would condense into liquids and then solids. Depending on the physical properties and the structure of the insulating material, limiting stress values may be reached bringing about fracture and distortion of the insulation material and possibly the containment system also.

In a naturally grown insulation material, moisture content is an important matter that has to be included in the specification and taken into account in the design. In this type of insulation, complete moisture removal may seriously impair the structural strength, therefore, limiting moisture content has to be tolerated. It is also important in the fabrication of the composite insulation, to define the orientation of the material to facilitate free and easy paths for moisture migration to be established and to provide the necessary trap spaces. In the fabrication process, environmental control is necessary to limit the moisture content in the insulating material. With naturally grown materials very strict selection is required to ensure good quality.

Most good insulation systems are maintained dry by vapour sealing methods or by dry air or inert gas circulation. The term dryness refers to a limiting dew point relative to the low temperature of the containment system.

FROST HEAVE AND FROSTING

In marine and land installations, low input heating devices are sometimes provided at predefined external locations in order to maintain the environment slightly above 0°C. The normal temperature that is aimed for is +5°C. This is done to ensure that any moisture in the environment does not freeze to form frost and ice. Frost and ice are insulation materials which tend to further reduce the overall heat leakage. The reduction of heat leakage into a low temperature environment when the ambient temperatures are low, must be examined relative to the materials used to fabricate the structural members of the containment system. Where limiting temperatures have been imposed on the structural members away from the low temperature surface of the containment system, then the insulation system should be so arranged to prevent lowering of the structural temperatures below their limiting values. This may be done by either increasing the thickness of the insulating material between the low surface temperatures of the containment system and the structural members concerned, or decreasing the insulation between the outer ambient and the structural members. Frost and ice formation does not help the latter case.

In some cases, the design of the low temperature environment itself may not allow free and easy heat flow paths to internal void spaces that are considered as ambient temperature bounding areas, e.g. transverse and longitudinal cofferdams in ships in which adjoining compartments may be cold compartments, or land tank foundations where no air gap is provided. In the above cases, external heating is arranged so as to accommodate economical structural material selection, especially as the ambient temperature may only be at low level for a short span of time. With some liqufied gas storage tank foundations, heating helps to establish an artificial ambient temperature that will ensure that frost is prevented and thus little or no soil disturbance, with its consequent damage to the base concrete structure, takes place due to frost heave (expansion of frozen soil).

HEATING ARRANGEMENTS

Heating arrangements may take the form of circulating hot fluids, inert gas or dry air, or by using electrical devices such as heating grids, etc. The safety requirements relative to the zonal division of spaces discussed later in the paper should be maintained. Heating should be arranged so as to provide ample heat to maintain the structural work at 5°C above the limiting temperature imposed by the design under normal and secondary containment conditions with reference to local minimum air and sea temperatures. The heating should be arranged so that, in the event of failure, at least partial heating could be maintained. For marine purposes, the heating load is so arranged that in the event of a partial failure at least 100 per cent of the theoretical heat load can be maintained by the remaining system. For a land installation a smaller stand-by heat load may be tolerated when a partial failure occurs.

When heating is provided, it should be periodically tested in order to ensure that it is functioning correctly. It is normal to provide sensing monitors for the outside environment. These sensing devices actuate audible alarms when limiting temperatures are being approached, and in some cases automatically switch the heating on. Where heating fluids are used, means should be provided to drain the system for periodic inspection and testing. Heating loads for the above system are considered as essential services when calculations for electrical and/or steam loads are made.

UNDERGROUND STORAGE SYSTEMS

Soil freezing within the water bearing strata has been used to build underground storage facilities for liquefied gas. Several papers have been presented on this subject and the author does not propose to go into details regarding this process. However, it can be briefly said that the frozen soil acts both as a container and insulation material. Designs may incorporate a lining of concrete membrane, prefoamed organic insulation material, or metallic lining. The freezing of the soil is achieved by circulating ammonia through tubes in the soil. The boring of the containment hole takes place after the soil is frozen to a thickness of several feet. Once boring has finished and the tanks completed, the liquefied gas provides the refrigerating effect to maintain the frozen soil as an insulating material.

Underground caves have also been used as storage containers for liquefied gas and cold stores for refrigerated foodstuffs. These types of containment systems would be grouped as containment systems with type 1, 2 or 3 insulation arrangement systems (*see* relevant parts of Appendix 'C' or 'D'), and would need to comply with the other requirements. In the above type of containment systems, equipment fitted in close proximity to the insulation should be of the demountable type which can be easily removed to a safe place outside the location for repair or service purposes. Hot work should not be encouraged and should only be carried out after extensive precautions have been taken.

Insulation, when provided, has to be compatible with the low temperature environment in all its phases, depending on what product is in the container. It has also to be compatible with the structural materials on which it is located. The compatibility tests that are normally conducted are stated in Appendix 'C' or 'D'. Minor decompositions of the insulating material may be tolerated as stated in a national standard or agreed to in a specification. It is normally accepted that some re-insulation would have to be undertaken should insulation decompose after leakage has taken place. Where insulation systems have to play a role in providing a satisfactory secondary containment in the event of leakage in the primary containment system, then decomposition of the insulation is not allowed.

Insulation may be located in a number of different ways to provide the resistance to heat flow into a low temperature environment. These locations have been listed in Appendix 'C'.

Relative to its location, some of the safety requirements called for have been stated in Appendix 'C' or 'D'. These requirements are discussed in the latter part of this paper.

Although the sphere is the vessel with the least surface area for a given volume, various considerations may limit the shape and size of the container to other geometrical forms.

HEAT LEAKAGE STUDIES

Heat transmission studies have to be made relative to certain prefixed ambient temperature levels. These temperature levels refer to maximum and minimum ambient temperature conditions and may be evaluated on the basis of a 20 or 40 year study of external environmental temperature and weather conditions for a particular geographical location. For marine installations the following ambient temperatures are considered:

Minimum air		+5°C	Still air conditions
,,	sea	0°C	
Maximum air		+45°C	
,,	sea	+32°C	

The above ambient temperature conditions are for world-wide service without geographical restrictions. Where ships are restricted to predefined geographical limits, maximum and minimum ambient temperatures are agreed.

Maximum ambient temperatures have to be defined in order to evaluate the maximum heat transfer loads and the temperature distribution patterns likely to be established in order to determine thermal stresses for different loading conditions that the structural members of the containment system are liable to encounter. Minimum ambient temperatures are defined in order to establish the evaluation of the structural steel work's temperature and, where materials have limiting temperatures temperature and, where materials have limiting temperature imposed, heating loads have to be evaluated to supplement the heat flow from the ambient. The problem is best illustrated in the transverse and longitudinal cofferdams of very large liqufied gas carriers and under foundations of shore storage tanks in order to prevent frost heave.

For occasional voyages into low ambient temperature areas, heating of the inner hull steel work in way of insulated areas of ships is permitted to maintain the steel work at or above its low limiting temperature.

Where the design philosophy calls for a number of protections between the primary low temperature containment system and the outside ambient, then it is normal to carry out temperature distribution studies for failure of each barrier. In all such cases, failure of one barrier should enable the successive barriers to protect the remaining intact structural members above its limiting temperature as imposed by the material considerations of the design. From the above discussions it will be seen that the insulation design and the temperature distribution patterns established play an important role in material selection associated with the structural design of the containment system.

CARGO CONTAINMENT AND VAPOUR RELIEF

With reference to heat flow into the cargo container, three methods of control are open to the designer:

(a) The judicious use of material with a good resistance to heat transfer to retard the rate of heat leakage.

(b) The use of a cooling media external to the cargo to act as a heat sink to either fully or partially absorb the heat ingress.

(c) Techniques where a combination of insulation and heat sink systems may be used to retard or stop the rate of heat leakage into the cargo.

Heat ingress into the cargo will result in the following:

(a) The liquid cargo will be elevated in temperature.

(b) Boiling will take place when the cargo is maintained in the tank as a boiling liquid.

(c) The superheating of the vapour in the vapour phase of the cargo.

Depending on the relief valve arrangements and settings associated with the container, the following may apply:

(a) If the cargo is to be maintained at a temperature lower than ambient, vapour relief will take place and can be dealt with as follows:

  (i) Discharge to atmosphere (if permitted).

  (ii) Reliquefaction—i.e. treated by a refrigeration process, either internally or externally orientated which returns the vapour into the liquid state.

  (iii) Disposed of in a burning unit.

(b) The pressure in the vapour phase will accumulate until equilibrium is established between the vapour and liquid phases. This depends on the magnitude of the pressure at relief and the physical properties of the liquid and its vapour phase (e.g. the latent heat of vaporization of the liquid cargo, etc.; the thermal inertia properties of the liquid and its vapour; the saturated vapour pressure properties of the liquid).

It is often assumed that venting or consuming the boil-off maintains a given vapour pressure and keeps the cargo at a constant temperature. This is not true. The heat ingress into the cargo results in boiling. The emerging flow of vapour into the atmosphere is dependent on the pressure difference between the outside atmosphere and the pressure within the containment space. If the atmospheric barometric pressure drops then the gas outflow rate will increase because of the decreased back pressure. In consequence the liquid cargo temperature at the liquid/vapour interface will appear to be elevated relative to its corresponding saturated vapour—evaporation will take place and will tend to build up a vapour pressure correspondent to that of the liquid cargo temperature. When a pressure rise takes place in the vapour phase (due to a rise in the atmospheric pressure) condensing will take place at the liquid/vapour interface and will tend to reduce the pressure to the saturated vapour pressure corresponding to the liquid temperature.

If vapour release were prevented by increasing the relief valve setting, then vapour generation would increase the vapour phase pressure on the liquid/vapour inter-phase. Some degree of condensation of the vapour would then take place because of a rise in the interface vapour pressure, and the temperature difference due to the disturbance between the balanced saturated vapour pressure corresponding to the liquid temperature of the cargo. The temperature of the newly formed condensed liquid would be at an elevated temperature relative to the mean bulk temperature of the liquid cargo, since heat ingress is taking place into the cargo and no escape of vapour is taking place.

It will be appreciated that what has been described in the last two paragraphs is time dependent, resulting in a delay in the sequence of operations. Secondly, by virtue of the insulating properties of the cargo liquid and vapour, an inertia is established in the sequence of heat transfer between these two. It will also be appreciated that none of these are step by step operations. In practice they are self regulating operations, very much dependent on the intensity of the heat flux into the cargo. Therefore, controlling the magnitude of the heat flux by means of insulation and heat sinks enables one to provide a better 'time dependent' control. The inertia effects of heat transfer can lead to stratification both in the vapour and liquid phases. The vapour in contact with the tank walls will be warmer than the vapour in contact with the liquid/vapour interface, hence the quality of the vapour will be from a super-heated state to a fully saturated state. In the liquid phase the variation will be from a warm liquid at its boiling temperature to a 'sub-cooled' liquid away from the heating surfaces of the container—i.e. the surface area at which the ingress of heat takes place into the cargo. The term sub-cooled is used purely relative to the hydrostatic pressure at the point under consideration and the corresponding saturation temperature of the liquid cargo for the hydrostatic pressure being established. From the above discussion it will be seen that:

(1) The shape of the cargo container and the distribution of the heating surface relative to the geometrical centre of the container will influence the distribution of the temperature isotherm patterns that are likely to be established in the liquid phase of the container.

(2) This will establish a stratification pattern which will be temperature and density orientated.

(3) The geometrical shape of the tank will promote or retard convection patterns of liquid movement and thus heat flow.

(4) In the vapour phase, temperature distribution patterns will be established and thus stratification.

(5) The pressure rise patterns of the vapour phase will depend on:

(a) Rate of heat ingress.

(b) Stratification in the vapour phase.

(c) Stratification in the liquid phase.

(d) The thermal properties of the liquid and vapour phase.

(e) The inertia to heat transfer in the liquid, vapour and liquid/vapour interface.

(f) Shape and size of the tanks and ratio of the vapour to liquid volume. The smaller the vapour space and the greater the temperature difference, the quicker will be the rate of pressure rise.

(g) The potential level at which the relief valve is set relative to the saturated vapour pressure of the liquid cargo—i.e. the smaller the potential difference level, the quicker relief valve setting pressure is reached; the greater the potential difference level the longer the time required to reach the relief valve setting pressure. Potential difference is equal to relief valve setting minus vapour space pressure.

(h) When the relief valve is set at the saturated pressure corresponding to the maximum ambient temperature then vapour relief will not take place.

(i) When relief valves are set at a pressure lower than that stated in paragraph (h) then vapour relief may take place—it will be directly time dependent on the potential difference between the saturated vapour of the liquid cargo and the relief valve setting. (The smaller the pressure difference the quicker vapour relief will take place.)

(k) Bearing in mind all that has been said in the preceding paragraphs, particularly in relation to the thermal inertia properties of the liquid cargo and its vapour, it should be noted that vapour relief can take place when relief valves are set below the vapour pressure corresponding to the maximum ambient temperature without the liquid cargo necessarily reaching a mean temperature corresponding to the saturation vapour temperature of the relief valve's pressure setting.

Cargo movement in a ship's containment system—due to ship movement—will disturb the hydrostatic pressure distribution within the liquid phase of the cargo and this will also influence vapour generation at the liquid/vapour interface. By controlling the free surface of the cargo (which is influenced by loading levels and the shape of the upper part of the containment system) and by the use of a free surface insulation system, vapour generation can be further controlled. Some liquefied gases moved by sea or stored on land are mixtures having different boiling points and densities. This complicates the problems of stratification, boil-off and pressure relief. Clearly, insulation and pressure relief for a containment system is related to a particular type of liquefied gas cargo. This must be specified at the design stage. If, for example, a containment system were designed for liquid propane of high purity, it may be unsuitable for a mixed 'liquid gas' cargo for the same or higher design temperature.

RELIEF VALVES

The relief valves are related to the insulation system because it governs the heat flow, especially in the event of an external fire. In considering the design and capacity of a relief system for a liquefied gas or chemical cargo the following points need to be taken into account.

(a) Overpressure caused by insulation loss.

(b) Overpressure caused by fire.

(c) Overpressure caused by chemical reaction of the cargo.

(d) Overpressure caused by improper operation.

Every relief valve has to perform two major functions:

(a) To relieve pressure in a containment system in excess of the set relieving pressure.

(b) To offer in the relieving condition an orifice flow capacity equal to that required by the Society's Rules within set pressure rise limits, at the temperature limits of discharge.

The estimation of the required relief capacity in pressure relieving systems venting vapour, is carried out on the basis of a recommended formula as stated in Chapter 8 of the Society's Rules for liquefied gas ships (paragraph 8.5). This formula takes into consideration:

(a) Rate of heat transfer to the cargo container under fire conditions.

(b) Structural configuration.

(c) Effect of the geometrical configuration on heat flux.

(d) Insulation, its value during a fire, and the role of water protection.

(e) Multi-range carriage of products.

The relief valve capacity is based on the formula

$$Q = F\frac{f \times E}{L \times C}\left(\frac{ZT}{M}\right)^{0.5} A^{0.82} \qquad (1)$$

Q = capacity in cubic metres/minute of air at standard condition of 0°C and 1.03 kp/cm².

F = fire exposure factor for different cargo tank types.

$\frac{E}{C}\left(\frac{ZT}{M}\right)^{0.5}$ = air equivalency of the cargo gas evolution.

Where E = a constant for air.

C = a constant based on relation of specific heats.

Z = compressibility factor of the gas at relieving conditions.

T = temperature in Kelvin at 20 per cent excess relieving capacity.

M = molecular weight of the cargo.

A = external surface area of the container.

L = latent heat of vaporization of the cargo at the relieving condition.

f = the heat flux due to fire.

It can be shown that the value $\frac{F \times f \times A^{0.82}}{L}$ is the equivalent weight of evaporation of cargo during the fire. The fire flux used in the above formula is

34,500 Btu/sq.ft/hr (93,564 kcal/sq.m/hr)

Therefore, the above formula may be rewritten as follows:

Q = cargo evaporation/hr ×
equivalent air constant of flow

Features other than those stated to be the causes of over-pressure in a liquefied gas/chemical cargo containment system such as the phenomena of 'roll over' or 'inversion' must be considered. It will be appreciated that the maximum heat flux that can be incorporated in the above formula is

1 × 34,500 Btu/sq.ft/hr

i.e. $\frac{1 \times 34{,}500}{60 \times 60}$ = 9.583 Btu/sq.ft/sec. (25.97 kcal/sq.m/sec.)

Assuming one second is equal to an instant of time this heat flux will give an evaporation of x lb of cargo per sq.ft. of cargo tank area and appropriately the relief valve capacity to relieve this capacity of cargo vapour.

In the event of a rollover phenomena depending upon various stratification features, temperature differences etc., evaporation in excess of x unit weight of cargo can be generated.

LIQUID FILLING RATIO

We now should consider another area where the heat transfer process plays a prominent part in the design of a container. Paragraph 8.3 of the Society's Rules and the IMCO Code (Chapter 15) deals with the volume to which a container may be filled with a low temperature liquid cargo. The sizing of relief valves only relates to vapour flow. Therefore, the Rules state quite clearly that the location of the relief valve should be wholly in the vapour phase, taking into consideration possible expansion of the liquid, and its level at all positions the tank is likely to assume at sea. The greater the temperature difference between the loaded cargo and the saturation temperature corresponding to the relief valve setting, the larger is the reserve volume for expansion of the liquid. The Code gives the following formula:

$$V_L = 0.98V\frac{d_R}{d_L} \qquad (2)$$

V_L = maximum volume to which tank may be filled.

V = volume of tank.

d_R = density of cargo at reference temperature.

d_L = density of cargo at loading temperature and pressure.

A careful examination of the formula reveals that the greater the potential difference between the vapour pressure of the cargo and the relief valve setting (designed to protect the container's membrane) the smaller is the quantity that is permitted to be carried in the container. Nevertheless, the Code also permits larger quantities of certain cargoes to be carried provided certain conditions are satisfied. One of these refers to the provision of additional relief valves.

Both at IACS and at IMCO there has been some controversy as to how the capacity of this additional 'satellite' valve is to be sized, and as to whether reduction in the relief capacity of the master relief valve could be permitted, taking into account the flow characteristics of the satellite valve. This has not yet been resolved by IACS or IMCO. Proposed methods of calculating the capacity of the satellite relief valve fall into two broad groups as follows:

(a) A capacity equal to the instantaneous volumetric evaporation of the excess cargo beyond liquid full condition. The liquid full condition being interpreted as 98 per cent of the tank volume at any temperature corresponding to the saturated vapour pressure being generated.
i.e. the capacity to discharge a weight of cargo equal to:

0.98 (VdR — Vs ds)

where V = Volume of the cargo tank at the reference temperature.

dR = density of cargo at the reference temperature.

Vs = Volume of the tank at a lower temperature to the reference temperature when liquid full conditions prevail.

ds = density of the cargo at the lower temperature to the reference temperature when liquid full conditions prevail

(b) The second method is to sequentially break down the evaporation process of the excess liquid beyond the liquid full condition (to master relief valve operation state based on a time dependent operation) so as to establish a controlled vapour relief mechanism. This step-by-step evaporative control of the liquid level within the cargo tank involves a number of approximations. One argument put forward to justify this approach is that the satellite relief valve is really part of a liquid level control mechanism.

This second method of calculation is really to deal with the evaporated (vapour) volumes of the expanding liquid. It has already been shown that vapour generation and heat transfer into a large geometrically complex

cargo containment system, is a complicated matter. Thus, any oversimplified calculations to accommodate for sequential evaporation is suspect. At this stage it appears that a recognized method of calculation based on the method applied to main relief valves, offers the best answer.

FIRE SAFETY

All designs of containment and manufacturing systems, whether marine or land based installations, are obliged to conform to predefined fire safety parameters. These requirements may vary in detail between land and marine installations mainly because of the availability of installation space on land compared with the lack of such spaces on ships. The land installation would be in a position to tolerate varying diminishing hazard areas between a flammably dangerous zone and a non-flammable safe zone. For marine purposes, a zone on board a ship within the cargo area is either a safe zone or a dangerous one relative to flammability. Within these zonal divisions, the insulation system has to be engineered to comply with the zonal requirements. In general, it may be stated that the philosophy on fire safety hygiene that an installation is required to comply with may be divided under the following headings:

(a) Constructional fire safety hygiene.

(b) Operational fire safety hygiene.

(c) Hardware required to fight and contain fires.

Constructional hygiene relative to fire prevention requirements is discussed in detail in the latter part of this paper. Operational fire safety hygiene refers to the training, education, and the daily discipline that is required in order to prevent fires being established and the hardware refers to the equipment that is available to fight fires.

Insulation systems are required to conform to a constructional code of hygiene with particular respect to flammability of the composite insulation materials relative to its location. Some of the essential requirements that the insulation would require to comply with are stated in Appendix 'C'.

Some comments on chemical compatibility and test requirements have been discussed in the earlier part of this paper and in Appendix 'C'. As regards non-combustibility, self extinguishing and flame retarding properties of the insulation, considerable study and discussions are taking place among national authorities and other institutions concerned with fire protection. Before any of the flammability retarding definitions are agreed to, it is important to agree to the definition of non-combustible (as regards fire terms, the new fire regulation definitions have been used in this paper), i.e. the term inflammable is replaced by the word combustible, etc. At present, the Inter-Governmental Maritime Consultative Organization (IMCO) definition on non-combustible materials is used by many classification societies as the standard definition.

Non combustible material means a material which neither burns nor gives off flammable vapours in sufficient quantities to ignite at a pilot flame or other sources of ignition when heated to approximately 750°C.

The present standards, such as the ASTM 1692 test procedures to evaluate self extinguishing and flame retarding properties, have not been adequate and it is felt that many additional factors will have to be taken into account, such as:

(a) The relationship between the severity and size of the source of heat and its relationship to the shape and size of the polymeric material.

(b) The capacity to dissipate heat within the body of the material exposed to a heating source.

(c) The establishment of suitable temperature gradients within the material relative to the exposed area.

(d) The release and breakdown of chemical vapours due to prolonged exposure in high heat content environments.

(e) The effect of any leaking out of a fire retardant additive on a short or long term basis.

(f) The effect of high heat environment on the mechanical property of the insulation and its adhesives, etc.

These are some of the many factors that may influence a test procedure method to classify and determine flame retarding, and self extinguishing properties of an insulation system.

Where insulation is fitted to a cargo tank in which the atmosphere is either inert or 100 per cent cargo vapour rich, it is considered that a fire hazard is minimal, and the insulation need not satisfy any requirements for combustibility. The fire hazard increases when the above conditions do not prevail and means of ignition are introduced. It is during construction and repair periods that a fire hazard may be present. During such periods it will be necessary to provide adequate fire precautions coupled with general cleanliness, until the cargo tanks are inerted and ready for gas purging.

Non combustible and self extinguishing properties may be highly desirable properties for an insulation material but such properties must be relative to the probability of fire involved. The addition of fire retardant chemicals should not greatly increase the levels of toxicity at high temperatures of the insulating material.

There are three main types of flame retardant compounds. These are based on phosphorus, halogens (bromide and chlorine) and antimony. Boron and nitrogen containing compounds are also used to a lesser extent, but the greatest efficiency is achieved by utilizing synergistic mixtures of flame retardants and these include antimony/halogens, phosphorus/halogens, boron/halogens and nitrogen/phosphorus. With glass reinforced plastics, fire retardancy can be provided by using reactive monomers during the resin manufacture or by the addition of non-reactive additives. Some of the drawbacks in the use of fire retardant chemicals are:

(a) The distinct risk involved in the lowering of the physical properties of the material.

(b) Increasing the corrosion problem due to additives such as those which contain chlorine, etc.

(c) Increasing the chances of embrittlement of the moulded material, etc.

The engineering design of the cargo containment and handling system should be so arranged as to exclude the possibility of spark generation and, therefore, the greatest concern arises when human beings are in close proximity to exposed insulated areas (internal or external to the containment system) and work involving heat input is carried out. This is really an operational discipline requirement rather than one calling for the elimination of the combustibility of the insulation.

The oxygen index test is becoming increasingly recognized as a test which grades materials with regard to their ability to sustain combustion in an enclosed environment. The test sample is burnt in an oxygen/nitrogen atmosphere and the oxygen content reduced to determine the minimum oxygen content which will just support combustion. The oxygen number indicates the minimum amount of oxygen necessary to support combustion relative to a normal atmosphere.

COMPOSITE INSULATION TECHNIQUES

As stated earlier, insulation systems, independent of their location, can be engineered to take specific advantage of the individual components in the system. In a composite insulation system, the component with the maximum resistance to heat flow is normally located near the cold surface and the one with the least resistance facing the warm environment

Where non-combustible, flame retarding or self extinguishing or other type of insulation is used, the material with the best resistance to combustibility is located on the warm side of the insulation system or that side which is exposed to human access.

In order to comply with mechanical protection and where self extinguishing or flame retarding or other types of insulation is used in association with metallic cover sheets, it is normal to provide a temperature quenching insulation material which is non-combustible between the interface of the metallic sheet and the main body of the insulation. The object of this temperature quenching material is to establish a temperature difference between the cover plates and the surface of the body of the insulation in the event of a fire. It is normal to limit the minimum thickness of this layer of non-combustible material to 3 mm.

The above form of temperature quenching technique of insulation protection may also be replaced by other materials that may provide the above protection in different ways. There are materials which are intumescent when exposed to a high temperature environment, i.e. the material swells to a foam and increases the distance between the hot source on one of its surfaces and the surface over the insulation, and thus establishing an effective temperature barrier. Other inert fillers such as inorganic hydrates which absorb heat energy for dehydration can also be used as a temperature quenching material.

PIPEWORK, VALVES AND INSTRUMENTATION

The major drawback with pipework insulation arises from the failure to provide adequate vapour sealing arrangements in way of pipe connections. Where large flanged connections are provided, the vapour sealing arrangement should effectively seal the ends of the insulation clear of the flanges and either leave the flanged connection bare or provide suitable enlarged insulation muff over the flanges and bolt connections. The pipework insulation and vapour sealing should be such as to prevent vapour migration along the pipe's body. Poor sealing arrangements have been the cause of extensive external corrosion of the pipework. The other type of pipework that presents difficulty are bellows pieces and expansion pipes. These pipes do need protection from the outside environment and frost and ice formation within their moving parts should be prevented. It is normal to provide a flexible vapour sealing arrangement which prevents moisture coming into contact with the colder parts of the pipework. Vacuum walled insulation could also be provided on pipework as an insulation system. Pipework in their stools should be adequately insulated in order to prevent heat leakage paths via the anchoring devices and should allow for expansion and contraction. It is also important to ensure that with low temperature insulation systems electrical continuity be maintained in order to prevent the generation and unsafe discharge of dangerous static electrical potentials.

Valves are specially designed for low temperature service and one of the desirable characteristics of a suitable valve for this service is that it has a low heat leakage capacity. A design frequently employed consists of extending the stem of an ordinary commercial valve and surrounding the assembly in a vacuum enclosure or in an insulation matrix, so as to reduce heat leakage and seizure due to ice formation.

TESTING AFTER COMPLETION (*See also* Appendix 'C')

The efficiency of the insulation system should be tested to ensure good workmanship, heat resistance property and design quality by means of:

(a) **Cooling down test**
At the first initial cool down of the low temperature container to the designed temperature, it should be shown that the cool down can be achieved safely.

(b) **Heat leakage test**
When the low temperature container has been fully loaded (if required) and maintained at its designed temperature, an attempt should be made to carry out a heat leakage test to ensure that the measured leakage compares favourably with the design values.

(c) **Boil-off handling**
Where liquefied gas is stored, tests should be carried out to ensure that the boil-off may be handled safely either by a reliquefaction plant or a burning system.

(d) **Heating arrangements**
The heating arrangements should be tested to ensure that the design requirements are complied with.

(e) **Test of safety equipment**
Where secondary containment requirements are needed in order to protect structural steel work, the following should be tested.
(i) Environment monitoring for cargo leakage.
(ii) Inerting arrangements for the containment spaces.
(iii) High level alarms and shut-off devices to prevent spillage.

(f) **Emergency discharge**
Tests should also be carried out to demonstrate that means are provided to handle the cargo in the event of a major mishap, such as failure of the insulation, primary containers, etc.

PERIODIC INSPECTION

The successful containment of a low temperature cargo is dependent upon the correct functioning of the insulation system, and to demonstrate this efficiency, the following records should be maintained for annual inspection by the regulating body.

(a) Cargo containment temperature (pressure if required).
(b) Structural materials temperature.
(c) Operating details of the refrigerating plant.
(d) Ambient temperatures.
(e) Cold spot inspection of all accessible spaces.
(f) Comments on cargo handling and containment difficulties experienced and the records of structural defects.
(g) Logs of sounding and dry spaces around the containment system.
(h) Periods when heating external to the primary cargo containment system is used.
(i) Pressure of the insulation spaces of cryostats.

At special surveys the following should be examined:

1. A more detailed examination of the insulation system, particularly powder insulation systems and those internally insulated.
2. Special attention should be given to areas where cold spots have regularly occurred and where structural repair work has been carried out.
3. Where possible, observation and testing should be carried out on insulation samples to determine composition and quality.
4. Where the insulation is not accessible, depending on operational results, access holes may be required to be cut to examine the composition and quality of the insulation system depending on the nature of the materials used for heat retardation purposes.

5. The base foundation and roof insulations must be checked for anchorage and movement. The special survey may be carried out after an interval of four or five years.

CONCLUSIONS

With many low temperature designs, insulation is still looked upon as an afterthought that need not be considered in depth until the containment structure has reached an advanced state of construction. It has yet to be appreciated that an insulation system plays an important complementary role in a low temperature containment system in order to prevent vapour relief. Its efficiency is the major contributing factor to the economy of the system. Any heat pump associated with the system should be related to the capacity of the insulation to retard heat leakage. Relative to the nature of the cargo in the containment system, quality control and testing are the final measurements of the workmanship of the system. The anticipative and corrective safety requirements are the results of agreed good practices. It would be advantageous for the interested parties (designers, contractors, etc.) to compile a code of practice to be used in the construction of a low temperature containment system, this code may well incorporate all or part of existing national standards.

If energy conservation is to be one of the major concerns of this world of ours during the last quarter of this century, then the insulating contractor, manufacturer and designer are going to play a vital role.

ACKNOWLEDGEMENTS

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APPENDIX 'A'

TYPICAL INSULATION ARRANGEMENTS

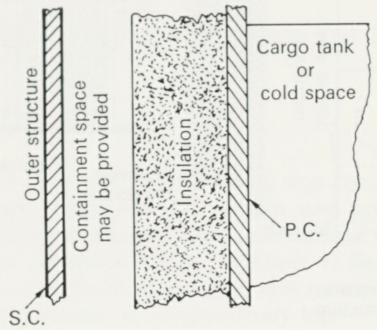
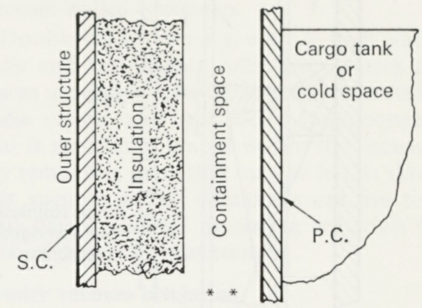
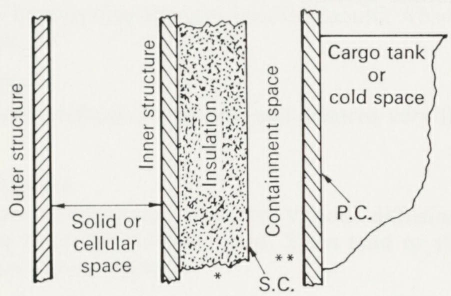


FIG. A1



**With a floating head storage tank. This may be used as a vapour draw off space

FIG. A2



*With suitable liquid tight insulation may be used for lower than −55°C onboard ships
**With a floating head storage tank. This may be used as a vapour draw off space

FIG. A3

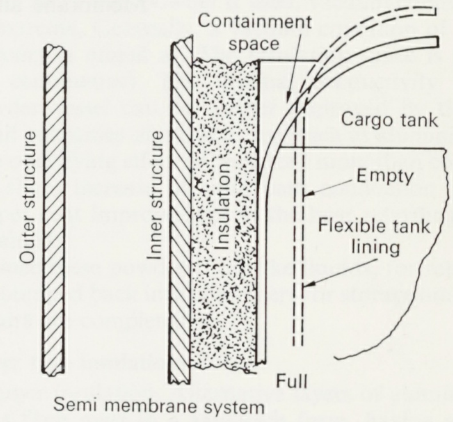


FIG. A4

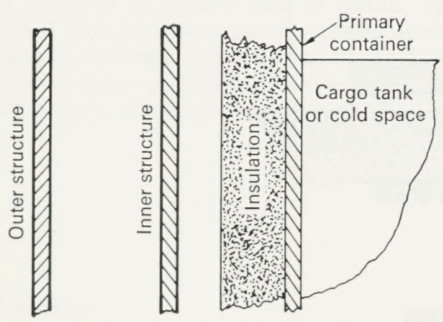


FIG. A5

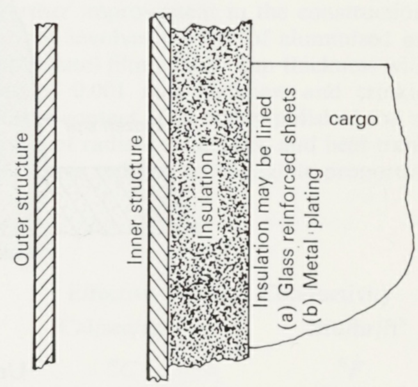


FIG. A6

P.C. = Primary container
S.C. = Secondary container

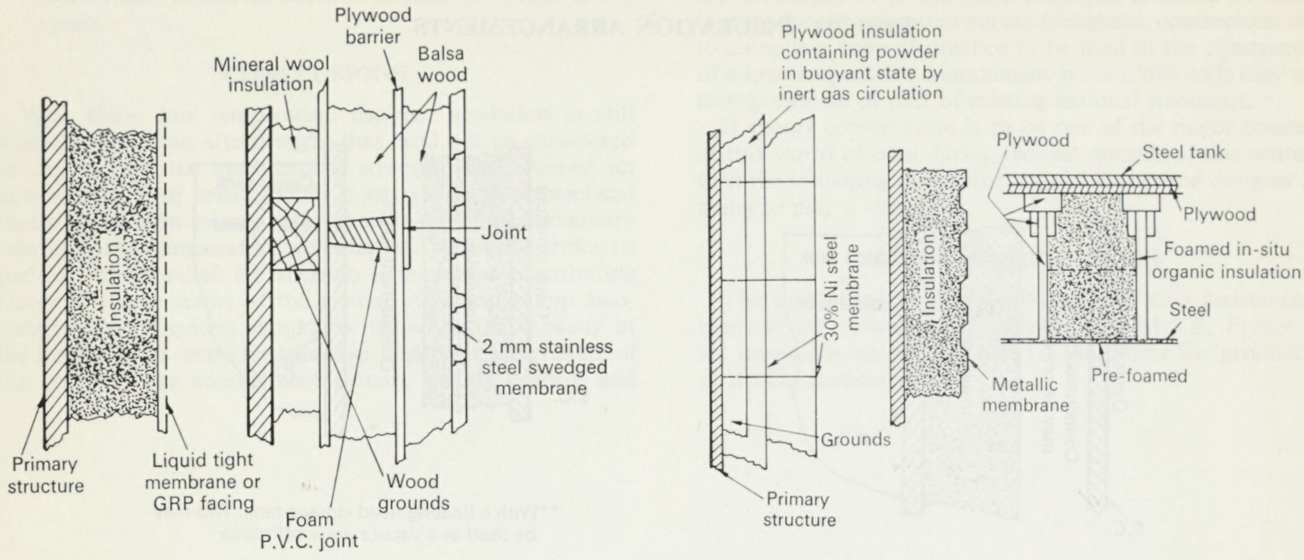


FIG. A7

Membrane and Semi-membrane systems

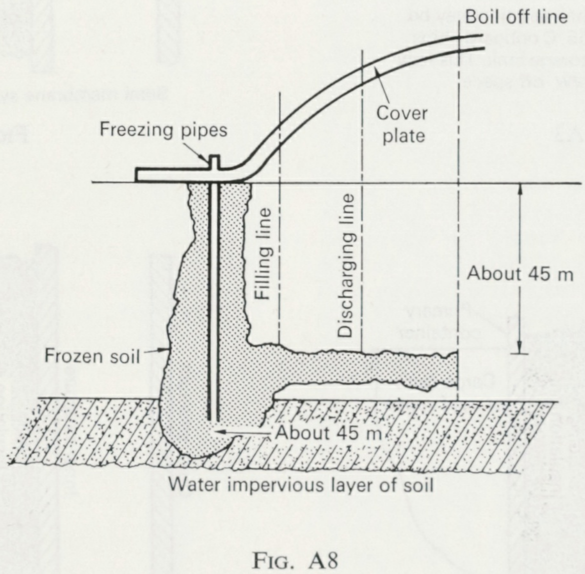


FIG. A8

Underground Storage

APPENDIX 'B'

INSULATING MATERIALS

Cork

Heavy and water absorbent, has good mechanical strength. In the event of fire it burns slowly.

Balsa wood

Has good mechanical properties combined with light weight.

Wood (hard)

Used quite often as frame-work for chocks and keyways.

Kapok

Can be used as mattresses.

Mineral fibres

Glass wool, rock wool, etc., are rot proof, non-combustible and easy to install. They are not airtight and are water absorbent. There is a considerable rise in the thermal conductivity if water gets entrapped within the fibres. If flammable gas diffuses into it, is difficult to gas free. Has no mechanical strength. The cost, however, is comparatively low.

Foam glass

Has good mechanical strength. It is of high density and is practically non-moisture absorbent.

Expanded rubber

This is made by injecting nitrogen into the mould. Absorbs very little water.

Expanded ebonite

Has very good mechanical strength and absorbs very little water.

Expanded polystyrene

It has satisfactory resistance to water. Vapour diffusion is low. Resistance to compression is good. Slabs tend to show shrinkage at low temperatures.

Expanded urea formaldehyde

May be moulded into slabs or used as light flakes. Has a relatively high hygroscopic content.

Expanded polyvinyl chloride

Has good mechanical properties. It is generally water and vapour proof. It is resistant to the action of oils, mineral salts, moulds and rodents.

Polyurethane

May be expanded in-situ, no matter what the shape of the structure to be insulated. It adheres well to metals, plastic materials and wood. This insulation may be applied by means of a special spray gun, but care must be taken to avoid lumps through applying too great a thickness in one spray, which will create a difference in thickness at the top and bottom of the surface. Polyurethane may be expanded by means of a heavy gas such as R12. This results in a considerable decrease in the coefficient of thermal conductivity.

Vacuum walled containers

Double-walled vessels with a high vacuum between the walls and with highly reflective surfaces facing the vacuum spaces are called 'Dewar vessels'—invented by James Dewar. These vessels may be made of glass, copper, steel, etc. Charcoal is sometimes placed within the vacuum space to absorb any remaining gases that may be left. It should be pointed out that vacuum walled containers are five times more efficient than plastic foamed insulating materials from the point of view of retarding heat transfer.

Powder vacuum insulation

In a Dewar vessel, heat transfer is entirely by radiation. By introduction of powder into the vacuum space, a reduction in the radiation heat transfer can be achieved, although there is an introduction of heat transfer by conduction, this form of heat transfer is negligible due to the tortuous path the heat has to travel along the points of contact of the spherical particles of the insulating powder. The powders used are light materials such as perlite, silica, aerogal, carbon black, diatomaceous earth, etc. When powder is used, vacuum conditions need not be extreme. Generally, a vacuum condition of 10 microns of mercury is aimed at. The insulating space is generally 4 in (10 centimetres). The thermal conductivity of a vacuum powder vessel can be further improved by the addition of small quantities of metallic dust such as aluminium or copper. The opacifying effect so produced more than compensated for the slight increase of solid path conduction and at least a 50 per cent improvement in the heat retarding effect can be obtained.

Since these powders flow like liquids, for repair work they are pumped back into containers for storage and re-used when repairs are completed.

Layer type insulations

Super insulation. Alternative layers of aluminium foils and glass fibre mats in a sandwich form, having as many as 80 layers per inch in a vacuum compartment greatly reduce the heat flow. The vacuum conditions have to be greater than that used for powder vacuum containers (about 1 micron vacuum condition instead of 10 microns).

A further improvement in the construction of these super insulations involves the use of aluminized mylar (polyethyleterephthalate) film of 0.25 mm thickness with an aluminium coating of 0.001 mm thickness and crinkled to minimize inter-layer contact. The highly polished foil surfaces act as a multitude of radiation barriers, and heat transmission by this mechanism is reduced to negligible proportions.

TYPICAL PROPERTIES

		Effective Thermal Conductivity	
		Cal/sec/cm^3	Btu/hr/ft^3
Insulation	*Gas Pressure*	*°C*	*°F*
Expanded Perlite	Atmospheric	600×10^{-7}	145×10^{-4}
Mineral wool	Atmospheric	800×10^{-7}	190×10^{-4}
Expanded Perlite	Vac. 10 Microns	60×10^{-7}	14.5×10^{-4}
Santocel	Vac. 1 Micron	40×10^{-7}	10.0×10^{-4}
Fine expanded Perlite	Vac. 1 Micron	20×10^{-7}	5.0×10^{-4}
As above with 40/60 w/w aluminium Santicel mixture	Vac. 1 Micron	8×10^{-7}	2.0×10^{-4}
Reflecting layer type	Vac. 0.1 Micron	1.5×10^{-7}	0.36×10^{-4}

PROPERTIES OF PLASTICS (TABLE 1)

	Material identification	Comment
1.	ACRYLICS	These resins are a class of plastics obtained by the polymerization of derivatives of ACRYLIC ACIDS. They are transparent, colourless and thermoplastic.
2.	CELLULOSIC PLASTICS	These plastic resins are cellulose based—cellulose acetate—celullose nitrate, etc.
2A.	CELLULOSE ACETATE	
2B.	CELLULOSE ACETATE BUTYRATE	
2C.	CELLULOSE PROPIONATE	
3.	EPOXIDES	Thermosetting resins derived from epichlorhydrin and bio-phenol-A used as structural plastics in surface coatings and as adhesives.
3A.	RIGID	
3B.	FLEXIBLE	
4.	FLUORINATED POLYMERS	A group of synthetic organic compounds which are usually non-flammable, chemically resistant to water and oil, e.g. polytherafluoroethene (TEFLON and FLUON).
4A.	FLUORINATED ETHYLENE PROPYLENE	
4B.	POLYTETRAFLUORETHYLENE	
4C.	POLYTRIFLUOROCHLORETHYLENE	
5.	MELAMINE FORMALDEHYDE	An organic compound which forms a thermosetting resin with formaldehyde.
5A.	UNFILLED	
5B.	ALPHA—CELLULOSE FILLED	
6.	NYLONS	It is a 'generic' term applied to any long chain of synthetic polyamide.
6A.	TYPE 6	
6B.	TYPE 6/6	
7.	PHENOL FORMALDEHYDES	Phenolic Resins—A very widely used type of synthetic resin produced by the condensation of phenols with Formaldehydes. Forms the basis of thermosetting moulding materials, also used in paints, varnishes and adhesives.
7A.	UNFILLED	
7B.	WOODFLOUR/COTTON FLOCK FILLED	
8.	POLYACETALS	Made by the polymerization of acetal.
9.	POLYCARBONATES	Resins.
10A.	LOW DENSITY	
10B.	HIGH DENSITY	
11.	POLYETHYLENES	Produced by the polymerization of ethylene. Tough waxy thermoplastic material used as an insulating material and where flexible plastics are required.
12.	POLYPROPYLENES	Plastic produced by the polymerization of propylene—used where a flexible plastic material is required.
12A.	CONVENTIONAL	
12B.	TOUGHENED	
13.	STYRENE COPOLYMERS	A copolymer of butadiene and styrene. Properties are generally inferior to natural rubber or the polymerization of styrene to form polystyrene—a thermoplastic material.
13A.	STYRENE-ACRYLONITRILE	
13B.	ACRYLONITRILE/BUTADIENE/STYRENE	
14.	UREA FORMALDEHYDE	Thermosetting resins, have good oil resistance properties produced by the condensation polymerization of urea and formaldehyde.
14A.	ALPHA CELLULOSE FILLED	
15.	VINYL POLYMERS	Polymers formed from vinyl compound which in turn was formed from the unsaturated univalent compound radical CH_2:CH, e.g. the polymerization of vinyl chloride CH_2:CHCL.
15A.	RIGID POLYVINYL CHLORIDE	
15B.	RIGID VINYL CHLORIDE/VINYL ACETATE	
15C.	RUBBER MODIFIED PVC	
16.	VINYLIDENE CHLORIDE POLYMERS	

PROPERTIES OF PLASTICS (TABLE 2)

PHYSICAL PROPERTIES

1 Burning Rate (Flammability) (ASTM D635)

None	0
Very slow	(1)
Slow	(2)
Moderate	(3)
Self extinguishing (*see* text)	(4)

2 Clarity Transparency

Transparent	1
Nearly transparent	2
Translucent	3
Opalescent	4
Opaque	5

3 Compressive Strength
(ASTM D695) lb/sq.in.
$\times 10^3$

4 Dissipation (Power) Factor
(ASTM D150) 10^6 cycles/sec
$\times 10^{-4}$

5 Dielectric Constant
(ASTM D150)
10^6 cycles/sec

6 Dielectric Constant
ASTM D149
Short-time $\frac{1}{8}''$ thick volts/mil

7 Effect of Sunlight
0 = None
1 = Very slight
2 = Yellow slightly
3 = Slight colour change
4 = Surface darkening
5 = Surface crazing*
6 = Affected
7 = Unsuitable
*Except black coloured

8 Elongation in Tension
ASTM D638
%

9 Flexural Strength
ASTM D790
PSI
$\times 1000$
* No break

10 Hardness
(Rockwell)
ASTM D785

11 Heat Distortion
Temp.
ASTM D648
of
$\times 100$

12 Impact Strength
ASTM D256
ftb/in
Notch 120D
at ambient temp.
* No break

13 Low Temperature Performance
Poor = 1
Fair = 2
Good = 3
Very Good = 4
Excellent = 5

14 Machining Quality
0 = Poor
1 = Fair
2 = Good
3 = Very Good
4 = Excellent

15 Modulus of Elasticity
(In tension) ASTM D767
psig $\times 10^6$

16 Mouldability
0 = Poor
1 = Fair
2 = Good
3 = Very Good
4 = Excellent

17 Permeability
at ntp. cc/cm^3/sec/mil/cm/Hg
at 25°C $\times 10^{-8}$

17A = Water Vapour

17B = Oxygen

17C = Carbon Dioxide

18 Softening Point (Vicat)
°C
MP = Melting Point
TP = Transition Point
DP = Decomposition Point

19 Specific Gravity
ASTM D792

20 Specific Heat
cal/°C/gm

21 Specific Vol.
ASTM D792
cu.in/lb

22 Tensile Strength
ASTM D683, 651
psig $\times 10^3$

23 Thermal Conductivity
ASTM C177
Cal cm/sq.cm/°C/sec
$\times 10^{-4}$

24 Thermal Expansion
ASTM D696
cm/cm/°C
$\times 10^{-5}$

25 Water Absorption
ASTM D570
$\frac{1}{8}''$ thickness
% 24 hours

PROPERTIES OF PLASTICS

TABLE 3

PHYSICAL PROPERTIES NUMBERS (TABLE 2 REFERS)

MATERIAL IDENTIFICATION NUMBERS (TABLE 1 REFERS)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	2	2	12/20	200/400	2.2/3.2	450/550	1	3–10	13–17	M85/M105	160–202	0.3/0.5	3	4
2A	2	1	2.2/36	100/1000	3.2/7.0	260/365	1	6–70	2–16	R35/R125	110–209*	0.4/5.2	3	4
2B	2	1	2.1/22	100/400	3.2/6.2	250/400	1	40–90	1–8–9.3	R31/R116	115–227*	0.8/6.3	3	4
2C	2	1	3.1/22	100/400	3.4/3.6	300/450	1	30–100	3–9–11	R20/R120	110–250*	0.5/10.0	3	4
3A	$\frac{3}{4}$	1/5	15/30	100/200	3.0/4.0	350/450	2	5–10	10–20	—	–570	0.3/0.9	3	3
3B	$\frac{3}{4}$	1/5	—	100/200	3.0/4.0	300/400	2	10–100	3–10	—	–140	0.5/1.5	4	2/0
4A	0	3	2.85	3	2.1	500/600	0	250–900	95	R25	—	*	5	2
4B	0	3/5	0.7/1.8	2	2.1	400/600	0	250–600	*	D50/D65	250*	2.5/4.0	5	2
4C	0	1/5	2.0	100	2.5	530/600	0	125–175	3.5	R110/R115	196–291*	3.5/3.6	3	–
5A	4	4	40/45	—	—	—	3	—	11–14	—	298	—	–	–
5B	4	3	25/43	270/450	7.2/8.2	300/400	3	06–0.9	10–16	M110/M125	400	0.24/0.35	3	1
6A	4	3/5	7/14	200/1300	3.0/7.0	440/510	6	90–320	8–16	R103/R118	260–340*	1.0/3.6	3	4
6B	4	3/5	7/16	200/600	3.6/6.0	385/470	6	60–300	8/13.8	R108/R118	300–360*	1.0/2.0	3	4
7A	1	1/3	10/30	150/300	4.5/5.0	300/400	4	1.0/1.5	12/15	M124/M128	240–260	0.20/0.36	–	1
7B	1	5	22/40	300/700	4.0/7.0	200/425	4	0.4/0.8	8.5/12	M100/M120	260–340	0.24/0.60	3	4
8	2	3/5	18	40/100	3.7	500	6	15–75	14–1	M94/R118	338*	1.4/2.3	3	4
9	4	1	11	110	2.6	400	2	60–100	11–13	M80/R125	290*	12/16	5	4
10A	1	2/5	—	5	2.25/2.35	460/700	5	90–650	*	D41/D46	105/121*	*	3	1
10B	1	3/5	2.4	3	2.25/2.35	800	5	50–800	2–3	D60/D70	140/180*	1.5/1.2	3	4
11	2	1/3	8.5/0.40	0.2/0.3	2.25/2.3	800	1	50–600	15/25	R85/R110	210/230	0.4/7.0	2	4
12A	2	1	11.5/16	0.1/5.0	2.4/3.1	500/700	7	1.0/2.5	12.00/17.0	M65/M90	150/235	0.2/0.5	1	1/2
12B	2	1	4.0/9.0	0.4/2.0	2.4/3.8	300/600	7	7/60	4.0/10.0	R50/R100	148/200	0.4/3.0	1/2	2
13A	2	1	14.0/17.0	2.0/10	2.75/3.1	400/500	2	1.5/3.5	14.0/19.0	M80/M83	150/235	0.35/0.5	1	2
13B	2	3	2.5/11.0	7.0/26	2.7/4.75	310/410	2	10/140	3.6/13.5	R30/R118	165/225	3.0/12.0	1	2.4
14	4	1/4	25.0/35.0	250/350	6.4/6.9	300/400	3	0.5/1.0	10.0/16.0	M115/M120	270/280	0.25/0.35	3	1
15A	4	1/5	8.00	6.0	3.0	425	2	2/40	13.5	R110	165	1.0/3.0	3	4
15B	4	1/5	—	—	3.0/3.5	1400	2	200/450	12.00	—	145/170	0.5/1.0	3	–
15C	4	1/5	13.0	140.0	—	1100	1	—	12.00	R105	160	15	3	–
16	4	1/5	23.0/2.7	50/80	3.0/4.0	400/600	1	Up to 250	4.200/6.2	M50/M65	130/150	0.3/1.0	3	2
—	–	–	—	—	—	—	–	—	—	—	—	—	–	–
—	–	–	—	—	—	—	–	—	—	—	—	—	–	–
—	–	–	—	—	—	—	–	—	—	—	—	—	–	–
—	–	–	—	—	—	—	–	—	—	—	—	—	–	–
—	–	–	—	—	—	—	–	—	—	—	—	—	–	–
—	–	–	—	—	—	—	–	—	—	—	—	—	–	–
—	–	–	—	—	—	—	–	—	—	—	—	—	–	–

TABLE 3

PHYSICAL PROPERTIES NUMBERS (TABLE 2 REFERS)

15	16	17A	17B	17C	18	19	20	21	22	23	24	25			MATERIAL IDENTIFICATION NUMBERS (TABLE 1 REFERS)
4.5	4	29–47 $\times 10^3$	3–4	29–28	80–90	1.17/1.20	0.35	23.7/23.1	7.11	4–6	5–9	0.3/0.4			1
0.65/0.4	4	–	–	—	70	1.23/1.34	0.3/0.42	22.5/20.6	1.9/8.5	4.8	8.16	1.9/6.5			2A
0.5/2.0	4	–	–	–	70	1.15/1.22	0.3/0.40	24.0/22.7	2.6/6.9	4.8	11.17	0.9/2.2			2B
0.6/2.15	4	–	–	–	—	1.18/1.24	0.3/0.40	23.4/22.5	2.0/7.3	4.8	11.17	1 2/2.8			2C
2.0/6.0	3	–	–	–	—	1.0/3.2	—	23	5.0/12.0	4.5	5–9	—			3A
—	3	–	–	–	—	1.2	—	23	1.4	4.5	5–9	—			3B
0.5/0.7	2	–	–	–	285/295 MP	2.14/2.17	0.28	12.85/12.66	2.5/3.5	5	8.3/10/5	0.0			4A
0.5/0.9	4	–	–	—	327 TP	2.1/2.2	0.25	13.09/11.95	2.5/6.0	6	9.22	0.0			4B
1.9/3.0	1	–	–	–	400 DP	2.10/2.15	0.22	13.09/12.98	4.6/5.7	—	0.7	0.0			4C
—	2	–	–	–	—	1.48	—	18.7	—	—	—	0.3/0.5			5A
13	4	–	–	–	—	1.47/1.52	0.4	18.8/18.2	7.13	7.10	4.0	0.1/0.6			5B
1.5/3.6	4	2800	0.12	0.5	220 MP	1.13	0.4	24.5/24. 2	10.2/12.0	—	8. 13	1.9/3.3			6A
2.6/4.0	2	–	–	–	264 MP	1.14	0.4	25.5/24.2	7.0/12.0	5.2/5.8	10–15	0.4/1.5			6B
7.5/10.0	1–2	–	–	–	—	1.25/1.3	0.38/0.42	21.2	7.0/8.0	3–6	2.5/6	0.1/0.2			7A
8.0/12.0	1–2	–	–	–	—	1.32/1.45	0.35/0.40	20.9/17.8	6.5/8.5	4–7	3.0/45	0.3/1.0			7B
4.1	2	–	–	–	175	1.425	0.35	19.5	10	5.5	8.1	0.12			8
3.2	2	–	–	–	165	1.2	0.30	23	8.5/9.5	4.6	7.0	0.3			9
0.17/0.35	4	420	15	55	85–87	0.191/0.93	0.55	30.2/29/6	1.0/3.3	8.0	16–18	0.015			10A
0.8/1.5	2	60	4	12	120–130	0.941/0.965	0.55/0.55	29.4/28.7	3.1/5.5	11/12.4	11–13	0.01			10B
1.3/2.0	4	160	4	35	150	0.9/0.91	0.46	31/29	4.2/5.5	3.3	11	40.01			11
4.6	4	4700	7/2	49/6	82/103	1.04/1.11	0.32/0.35	26.4/24.8	5.0/12.0	2.4/3.3	6.8	0.03/0.4			12A
2.5/4.5	4	–	–	–	78/100	0.98/1.10	0.32/0.35	28.1/25.2	2.5/7.0	1.0/3.0	3.4/21	0.1/0.3			12B
4/5.6	2	–	–	–	85/103	1.075/1.10	0.32/0.34	25.8/25.2	9.5/12.0	2.9	6.8	0.2/0.3			13A
1.0/4.1	2	–	–	–	85	0.99/1.10	0.33/0.40	28/25.2	2.5/9.0	1.48/8.6	2.7	0.4/0.8			13B
15	4	–	–	–	—	1.47/1.52	0.4	18.8/18.2	6.0/13.0	7.10	5.0	0.05			14
3.5	1/2	630	0.47	0.4	82	1.38/1.4	0.2/0.5	20.1	8.5	3.5	7.0	0.08			15A
—	1/2	–	–	–	—	1.37/1.45	0.2/0.5	20.4/19.1	7.5/8.5	3.7	5.0	0.10			15B
6.0	1/2	–	–	–	78	1.35	0.2/0.5	20.5	6.0	4.5	19.0	0.10			15C
0.5/0.8	4	5.5	0.009	0.12	71	1.65/1.72	0.32	16.8/16.1	3.0/5.0	3.0	—	—			16
—	–	–	–	–	—	—	Btu/lb/°C	—	—	—	—	—			17
140	–	–	–	–	—	8.5	0.09	3.5	46.3	2900	0.199	—			17A
300	–	–	–	–	—	7.87	0.11	3.52	70.6	1500	0.126	—			17B
290	–	–	–	–	—	7.85	0.11	3.7	73.2	1200	0 112	—			17C
103	–	–	–	–	—	2.82	0.23	10.9	12.0	5200	0.240	—			17D
103	–	–	–	–	—	2.8	0.23	9.9	35.8	3500	0.225	—			17E
160	–	–	–	–	—	8.98	0.09	3.12	58.2	2000	0.178	—			17F

APPENDIX 'C'

LIQUEFIED GAS SHIPS INSULATION REQUIREMENTS

DOCUMENT AS PRESENTED TO I.A.C.S.

1 INSULATION

1.1 For the purpose of this code, materials that are used exclusively for controlling heat flow without contributing in any significant way to the structural strength of the containment and handling systems of liquefied gas carriers are grouped under the above heading.

1.2 Insulation, when provided, shall be compatible with the cargo in all its phases and any materials with which it will be in contact. The administration may, at its discretion, tolerate minor decomposition of the insulating material when used in association with some of the cargoes that the ship may be permitted to carry, except where it is also designed as a primary container or secondary barrier.

1.3 The insulation may be designed to fulfil the following additional services.

(a) As a secondary barrier.

(b) As a primary container for liquefied gases down to −50°C temperature.

(c) As a primary container for liquefied gases below −50°C temperature.

1.4 For the purpose of this code the following definitions will apply.

(a) Non combustible:— as defined by SOLAS.

(b) Self extinguishing:— to be defined by a national standard.

(c) Fire retardant:— to be defined by a national standard.

(d) Combustible:— any material that does not comply with the requirements for non combustibility.

(e) Decomposition:— any material that ceases to maintain its physical properties when raised to a temperature of 100°C for a period of 1 hour, when used on equipment at or below +60°C.

(f) Normal properties:— the design properties that a material is expected to exhibit between designed temperatures.

(g) Vapour seal:— this may be of rigid material or mastic compound which is impervious to the transmission of water vapour.

(h) Mechanical protection:— protection against physical damage.

(i) Oxygen Index:— minimum O_2 required to sustain combustion.

(j) Non load bearing insulation:— insulation that is required to carry its own weight and loads less than 5 per cent of that required to cause permanent deformation.

(k) Load bearing insulation:— insulation that is required to carry its own weight and load in excess of 5 per cent but less than 20 per cent of that required to cause permanent deformation.

(l) Gas free spaces:— are spaces free of cargo vapour or liquids which are combustible.

(m) Gas dangerous spaces:— are spaces which contain cargo vapour or liquid which is combustible.

(n) Inerted spaces:— are spaces where the oxygen is less than 18 per cent by volume (relative to human habitation).

1.5 **Location of insulation**

1.5.1 **Insulation on surfaces with a temperature below 100°C**

Type 1 Where the insulation is located in such a manner that it is continually exposed to the cargo's vapour or liquid phase. The insulation may also be lined by a non-metallic lining as a part of the insulation system.

Type 2 Where the insulation is located outside a metallic lining which has been considered as a membrane or semi-membrane tank system requiring a full secondary barrier.

Type 3 Where the insulation is located outside a self-supporting or a semi-membrane tank requiring a partial or full secondary barrier and with the exposed environment inerted.

Type 4 Similar to type 3 but with the insulation lined with a non combustible facing.

Type 5 Similar to type 3 location and where no form of secondary barrier is required and thus where normal air may be circulated.

Type 6 Where the insulation is on the cargo tank and exposed to the normal outside environment.

Type 7 Where the insulation is located on equipment and pipework, etc. which is located in a non gas dangerous space.

Type 8 Where the insulation is located in a gas dangerous enclosed space outside the cargo tanks.

1.5.2 **Insulation on surfaces with a temperature above 100°C**

Type 9 Insulation on surfaces with temperatures in excess of 100°C in gas spaces.

Type 10 Insulation on surfaces with temperatures of 100°C in gas free spaces.

1.5.3 **Principal requirements of insulation material relative to their location**

See Table 1.5.3

1.5.4 **Composition of insulating materials**

Insulating material may be non combustible, self extinguishing, fire retardant, or a sandwiched combination of the above and other materials.

1.5.5 **Compliance of insulation requirements**

Insulation material when composed as stated in 1.5.4 can be considered in its composite form for the requirements of this code as required by paragraph 1.5.3.

1.5.6 **Powder insulation systems**

Where powder or granulated materials are used for insulation purposes, the arrangement should be such as to prevent compacting of the material due to vibration. The design should incorporate mechanical means to ensure that the material remains sufficiently buoyant to maintain the required thermal conductivity and also prevent any undue increase of pressure on the containment system.

TABLE 1.5.3

PRINCIPAL REQUIREMENTS OF INSULATING MATERIALS

RELATIVE TO THEIR LOCATION

LOCATION TYPE

	1	2	3	4	5	6	7	8	9	10
Chemical Compatibility	X	X	X	X	X	X	X	X	X	X
Non-Combustible or	0	0	0	0	X	X	X	X	X	X
Self Extinguishing or	0	0	0	0	X	X	X	X	X	X
Fire Retardant	0	0	0	0	X	X	X	X	X	X
Load Bearing	0	0	0	0	0	0	0	0	0	0
Non-Load Bearing	0	0	0	0	0	0	0	0	0	0
Vapour Sealing	0	0	0	0	0	X	X	X	0	0
Mechanical Protection	0	0	0	0	0	X	X	X	X	X
Normal Properties	X	X	X	X	X	X	X	X	0	0
Decomposition	X	X	X	X	X	X	X	X	0	0
Non-Spark Generating Mach./or Control in Operation	X	X	0	0	0	0	X	B	X	0
No Hot Work Allowed	X	A	A	A	A	X	X	X	X	X
Demountable Equipment	X	0	0	0	0	0	0	0	0	0
O_2 Index	X	X	X	X	X	X	X	X	X	X

X To be complied with
0 May be complied with
A Special precautions required
B Not applicable

1.6 Heat transmission studies

1.6.1 Primary barriers and cargo containment systems

1.6.1.1 Heat transmission studies for normal services required shall assume minimum ambient temperatures of:

Ambient Air +5°C (+41°F) (still air)
Sea 0°C (+32°F) (still water)

The maximum ambient condition shall be:

Ambient Air +45°C (+113°F) (still air)
Sea +32°C (+90°F) (still water)

(See additional notes for Class I Cargoes (Chlorine)).

1.6.1.2 The above conditions are for world wide service without geographical restrictions.

1.6.1.3 Transverse and longitudinal parts of the ship's hull sandwiched between insulated cargo tanks, may be provided with approved heating arrangements in order to maintain the steel work above the allowable limiting temperature at the minimum ambient temperature stated in 1.6.1.1 world wide service without geographical restrictions.

1.6.1.4 For occasional voyages into low ambient temperature areas, an approved means of heating the inner hull steel should be provided in order to maintain the steel work at, or above, its lower limiting temperature. Where heating is normally provided as stated in paragraph 1.6.1.3 under normal service conditions, the design heating load should be increased to allow for occasional voyages as stated above.

1.6.2 Secondary barriers and cargo containment systems

1.6.2.1 Heat transmission and temperature distribution studies with the cargo at the full or partial secondary barrier should be submitted for both the maximum and minimum ambient temperature conditions.

1.6.2.2 Where partial secondary barriers are provided, the cooling effect of the rising boil-off vapour after leakage on other parts of the containment space, should be considered in the heat transmission studies.

1.6.3 **Heat transmission and temperature distribution studies** shall be submitted for the following conditions.

(a) Total heat flow into the cargo at maximum ambient conditions as stated in 1.6.1.1 when the cargo carried is

at minimum temperatures assigned to the cargo tank or tanks or ship's cargo containment system.

(b) Temperature distribution studies for both maximum and minimum ambient temperatures, and should include the following information.

(i) Longitudinal and transverse hull steel bulkhead temperature above and below the load water line.

(ii) Temperatures in way of thermal bridges between the hull and the cargo containment systems.

1.7 Heating arrangements for the inner hull structure

Heating arrangements should comply with the following requirements.

(a) The heating arrangements should provide ample heat to maintain the steel work above its limiting temperature under normal and secondary cargo containment service conditions with reference to the local ambient air and sea conditions considered.

(b) The total heating capacity should be at least $1.2 \times$ the theoretical heating load required.

(c) The heating arrangements should be arranged so that in the event of failure sufficient heating can be maintained equal to not less than 100 per cent of the total heat load.

(d) The above heating loads shall be considered as essential loads for the safe operation of the ship.

(e) All heating systems shall be seen to operate at least every month by the ship's staff and records of the ambient air, sea, and compartment temperatures shall be maintained and be available for examination.

(f) The engineering of the heating services should comply with the classification society's requirements.

1.8 Insulating systems

In determining the arrangements of the insulation systems, calculations should be submitted to evaluate the following:

(a) The maximum boil-off likely to be encountered when a full cargo is carried (primary and secondary containment conditions).

(b) That the capacity of the reliquefaction or refrigeration plant is adequate to maintain temperature/pressure control.

(c) The cooling down thermal loads when preparing to receive a liquefied gas cargo aboard the ship with maximum ambient air and sea conditions.

(d) Where boil-off venting to the atmosphere is not allowed, and where no shore return facilities are available, the insulation and reliquefaction plant capacity should be sized in order to meet designed cooling down rates of the cargo tanks without venting to atmosphere.

1.9 Demountable equipment

Where insulation is located in a type 1 location, equipment fitted in close proximity should be of the portable type which can be easily removed to a safe place outside the location for repair or service purposes.

Hot work should only be carried out after extensive precautions have been taken.

1.10 Insulation specification

The quality control, in-situ testing and in-situ fire precautions to be taken during construction should be submitted for approval.

1.11 Testing after completion

The efficiency of the insulation should be tested to ensure good workmanship, heat resistance, and design qualities by means of:—

(a) **Cooling down test**

At the first initial cool down of the cargo tank to the temperature notation assigned to the tank or ship. The test should demonstrate that cool down can be achieved in a manner which minimizes thermal stresses.

(b) **Heat leakage test**

When a full load of cargo has been carried at the minimum temperature between a loading and discharging port.

(c) **Boil-off handling**

Tests to ensure that the boil-off can be handled satisfactorily

(d) **Heating arrangement**

The heating arrangement should be tested to ensure that the design requirements are complied with.

(e) **Test of safety equipment.** Associated with the protection of hull steel work.

1. Flooding.
2. Environment monitoring for cargo leakage.
3. Inerting of containment spaces.
4. High level alarms and shut-off of devices to prevent spillage.

(f) **Emergency discharge**

Tests should also be carried out to demonstrate that the cargo pumps can satisfactorily handle the cargo, particularly in the event of a major failure such as insulation, primary containers, etc.

The above tests should be carried out to the satisfaction of the regulating authority.

1.12 General insulation tests

The insulating material should not be adversely affected by the cargo. Samples of the insulating material should be tested in the cargo for solubility, absorption and shrinkage. The sample should be checked for the above effects at intervals not exceeding one week for a total period of about six weeks.

Any adhesives, sealers, coatings or vapour barrier compounds used in conjunction with the insulating material should be similarly tested to ensure that they are compatible with the cargo and insulation.

Mechanical tests should be carried out on the insulation in order to determine its tensile and compressive load bearing properties.

The insulation's hygroscopic properties should be determined when immersed in water at 0°C (32°F), 30°C (86°F), and in steam at atmospheric pressure.

The thermal expansion properties of the insulation relative to the material to which it is to be fixed should be considered in the design.

1.13 Mechanical protection on type 6 located insulation

The mechanical protection on insulation in type 6 location must be non-combustible. Where the protection is of the metallic type, the insulation should be non-combustible or, alternatively, a non-combustible temperature quenching insulating material should be inserted between the metallic lining and the main insulating material. The minimum thickness of this layer of non-combustible material is to be 3 mm.

APPENDIX 'D'

INTERNAL INSULATION SYSTEM

PROTOTYPE TESTING REQUIREMENTS

DOCUMENT AS PRESENTED TO I.A.C.S.

These requirements are intended for systems where the insulation is used for cargo containment, the cargo being in direct contact with the surface of the insulation. The requirements also apply where the insulation is covered by a plastic type integral outer member.

The tests are shown under the headings of Sections A, B and C.

Section A lists the small scale individual tests to be carried out on the insulation materials that are used in the construction of the primary and secondary containment systems.

Section B lists the requirements associated with the building and testing of a test tank when such testing is called for by the classification society. The requirement to build a test tank will be dependent upon the type of system proposed.

Section C lists the full scale tests.

SECTION A

The tests in this section are to be carried out with each cargo in the class notation unless agreed otherwise.

The classification society may also call for certain tests to be carried out with inert gas, or any other material or product that may be in contact with the insulation.

General tests

1. A number of samples of the insulation should be subjected to the liquid cargo temperature and a pressure of 1.75 kg/cm^2 over a period of 15 days. Checks should be made for dimensional stability, absorption, solubility, etc.
2. One face of a sample of the insulation should be subject to the pressures and temperatures stated in (1). Any passage of liquid or vapour should be detected by means of a temperature sensing device and a gas analyser over a period of 15 days.
3. In a dry test the cellular tightness of the insulation material should be tested on a standard test piece—preferably a helium gas leak detector.
4. **Closed cell content test**

   To be measured after subjecting the sample to liquid cargo temperature and 2.1 kg/cm^2 for a period of 28 days. The testing method is to be to the classification society's satisfaction.
5. **Adhesion test**

   Where the insulation adheres direct on the steel work of the tank hold, it should be shown that the bond will not fail when the system is subjected to the hydraulic and dynamic loading of the ship's motion. The bond between the insulation and steel work should be stronger than the insulation material. Other adhesion surfaces in the system will require to be strength tested. Tests to be carried out at ambient temperature and also with the free surface of the insulation at cargo temperature.
6. **Mechanical tests**

   Samples of insulation material should be tested for

   (a) Tension.

   (b) Compression.

   (c) Shear.

   (d) Modulus of elasticity, rigidity, bulk modulus and Poisson's ratio.

   (e) Creep.

   (f) Ageing.

   Where the system incorporates barriers, void spaces, skins, etc., tests similar to the above may be called for. The above tests are to be carried out at ambient and cargo temperatures.

   Ambient temperature may be taken as 0°C or 20°C.

   All tests should be on samples that are within the specification for the materials to be used in the cargo containment systems of the vessel.

   When the insulation is foamed in-situ either by spray equipment or by mixture methods behind shuttering, the object should be to cut representative samples in the normal, longitudinal and transverse direction of foaming.

   A minimum of five specimens should be used to procure a range of tests for the same type of specimen and test procedures.

   The object of these tests should be to establish a range of results to justify a design criteria for a stress level.

7. **Thermal property test**

   These tests should be conducted in the laboratory to determine the following:

   (a) Variation of thermal conductivity with foam density and temperature.

   (b) The effect of ageing on the thermal conductivity test.

   (c) Specific heat of the foam relative to the foam density.

   (d) The establishment of procedures to limit the variation of insulation thickness at application site.

   (e) Coefficient of cubical expansion, etc.

8. **Fatigue test**

Strain reversals associated with the anticipated stress reversals in the inner hull should be calculated and applied to samples of insulation material at both ambient and cargo temperature until failure of the insulation occurs. This test should be in the form of a high speed fatigue test. The tests should be carried out until failure of the insulation materials takes place or at least 8×10^6 cycles are completed. Care should be taken to maintain specimen at the test temperature or compensation should be made for any temperature rise.

9. **Pressure cycling tests**

The insulation material should be subjected to a pressure cycling test varying from a pressure of P_1 to P_2 at the cargo temperature. The number of cycles should be 8×10^6. The pressure P_1 = Cargo tank MARVS: $P_2 = 1.2 \times$ Max. design pressure P_0 as stated in the Code. The deterioration of the insulation material should be measured by determining the normal cell content before and after the test.

The extent to which liquid penetration takes place should be measured.

10. **Thermal cycling test**

The insulation material should be subjected to a thermal cycling test varying in temperature from +20°C to the cargo temperature. A minimum of 600 thermal cycles should be carried out.

The deterioration of the exposed surface of the insulation material should be measured by determining the normal cell content before and after the test. The test should be carried out on insulation with a normal surface and also with a surface representing a damage condition.

11. Crack propagation test

Tests should be carried out as stated in 8, 9 and 10 but with the following cracks initiated. The cracks should be sharp knife cuts to the following depths.

(a) 50 per cent of the standard foaming height of each layer of foam.

(b) 100 per cent of the standard foaming height of each layer of foam.

(c) 150 per cent of the standard foaming height of each layer of foam.

Three patterns of cracks as shown should be inserted. (*See* Fig. D1.)

12. Flammable properties test

The Society's normal requirement for insulation is that it is self-extinguishing.

13. Chemical compatibility test

The object of these tests is to ensure that the insulation is chemically inert to:

(a) The cargo at all its temperatures, i.e.

as a liquid at cargo temperature

as a vapour at cargo temperature

as a vapour at $+20°C$.

(b) The normal atmosphere—dry and saturated.

(c) Inert gas used for cargo handling purposes.

These tests should not be confused with tests stated previously since they are essentially a structural stability test.

With reference to (b) the normal ageing test satisfies these requirements.

14. Toughness test

A toughness test with high denisty plastic material should be submitted.

It is doubtful if any meaningful results would be obtained from Izod or the drop weight test for light density foams. The Society is aware that investigations have been made on critical crack lengths of heavy density insulating materials by adopting testing machines used in the paper and cotton industries to investigate the toughness and tearability of these materials. The Society would be pleased to investigate such results, which should be carried out at the cargo temperature.

15. Secondary barrier

A complete secondary barrier in accordance with the Society's Rules for Ships for Liquefied Gases is normally to be provided. Proposals for designs incorporating a reduced secondary barrier will be considered.

(a) The containment should be engineered such that damage to the primary barrier will not normally also give rise to damage to the secondary barrier. This does not necessarily mean that the two barriers must be kept at any fixed distance from each other.

(b) A programme for proving the secondary barrier requirements will need to be submitted.

(c) Where the insulation design precludes inspection of the secondary barrier at periodical surveys the design would still be acceptable to the Society provided adequate quality control is observed during construction, associated with built-in engineering facilities to test principal parameters in order to determine the integrity of the secondary barrier. In addition to this, the prototype testing should be objectively designed to seek assurance on probable life cycles of the insulation system relative to the containment design and cargoes that are to be carried. Where the hull structure is constructed of materials other than steel (i.e. prestressed concrete), the classification society's normal criteria associated with a minimum hull temperature of minus 20°C may not be applicable, however, the secondary barrier alarm system, to indicate that the barrier is at cargo temperature, will be regarded as essential

Engineering utilities within the cargo tank

All fittings and equipment within the cargo tank will have to be critically examined to assess the probability of any form of hot work being required in service and/or to the continued presence of non-disciplined workmen within the tank for repair or modification purposes. The term undisciplined has been used to differentiate those who do not come under the daily discipline of the Master of the ship even if not associated with hot work. In this connection it should also be stated that anchoring devices attached to the strength member of the hull and protruding out of the insulation must be initially sealed in association with the primary barrier in order to maintain the liquid or vapour-primary barrier interface well above the location of the secondary barrier.

Gas freeing

Depending upon the results of the tests, it may be necessary to design facilities to heat the internal environment and ventilate the tank to ensure the extraction not only of liquid penetration into damaged surface areas, but also vapour, so as to ensure that any vapour remaining after the exercise has been completed is so small in quantity that its natural percolation into the atmosphere within the tank will neither be toxic to human beings nor generate a flammable atmosphere, i.e. any resulting cargo gas/air mixture is well below the lower flammable limit of the cargo in air. This will depend on the depth of liquid/gas penetration into a damaged area due to the establishment of open cells within the insulation.

The above utilities should have a capacity large enough to deal with a major surface damage such as the total surface area of the tank.

Damage detection and repair procedure

In addition to establishing good quality control according to a well drawn up insulation specification, the testing should also investigate the likely fault conditions that could develop while insulating, and the resulting deterioration in the insulation must be studied and investigated. This must be accompanied by methods of detection by observation, and as to how repair is to be conducted in order to remedy the fault or damage conditions. It would be advisable to establish repair conditions after the normal data has been obtained in order to rigorously test the success of the repair work.

Non-destructive testing

Where repairs have been carried out, a means of repair verification, using non-destructive testing methods should be developed.

National standards

In addition to the tests now stated, relevant national standards may also be used.

SECTION B

Section A has listed the small scale individual tests on the insulation materials that constitute the primary and secondary containment system. This section addresses itself to the building of a test tank or other model test and the tests associated with it when such testing is required by the classification society.

(a) **Test tank particulars**

The minimum internal capacity of this tank should not be less than 10 cubic metres, i.e. 0.98 per cent of its internal volume should not be less than 10 cubic metres. Larger tanks may be used.

The test tank is to be lined with the insulation system to be used in the actual design.

In order to accelerate testing procedures several similar test tanks may be used. The test tank should, as far as practicable, incorporate the construction irregularities associated with the design of the main cargo tank so as to demonstrate the confidence of the primary and secondary containment system at the points of geometrical irregularity.

The tank should incorporate all the possible geometrical variations that the average cargo tank is likely to encounter in its design, such as:

A tank side.

A tank top.

A hatch corner.

A transverse bulkhead connection.

An anchoring device to the strength member of the containment system located at top, bottom and side.

The as-fitted test tank, its instrumentation and testing procedures should be submitted to the Society for approval prior to the commencement of the test. A system of witnessing the major salient features of the tests by the Society should be instigated.

It is also possible to carry out large scale tests on flat areas without building a test tank. This is permissible provided the tests reveal the design limitations of the system. The design limitations are those called for by the classification society and as stated below.

Testing fluid

The testing fluid should be that in the list of cargoes which has the lowest carrying temperature. Fluids other than those in the list of cargoes will be considered for use as a testing medium (i.e. liquid nitrogen).

The tests are to be carried out as follows.

PART I

The insulation system is to be in accordance with the specification. The object of these tests is to prove the 'as constructed' system.

(a) **Thermal cycling test**

The object of this test is to simulate the cooling, loading, discharging and warming conditions that the system is likely to experience throughout its life. Because of the thermal inertia of the insulating material in an internal insulation system and the time that it is likely to take to stabilize to the established temperature gradient or to normalize to ambient temperature conditions, a system of thermal cycling periods should be devised to minimize the testing time and yet establish a representative pattern of the thermal cycling life that the system is likely to experience in service. *See* Fig. D2. A total of $1.2 \times 20 \times 20 = 480$ cycles should be completed.

Heat balance test

This test should be repeated at least twice. Once before the thermal cycling testing and once after the end of the tank test. The object of this test is to evaluate the practical overall thermal heat transfer property of the insulation part of the containment system. The reason for doing at least two tests is to evaluate the degree of deterioration of the insulation system.

Since the boil-off measurement method is quite a popular means of evaluating insulation efficiency, a period of liquid cargo agitation should form a part of the testing period. The stabilization period is vital if any purposeful meaning is to be obtained from the results of the test. (*See* Fig. D3.)

The test tank should preferably be in the open, exposed to the normal atmospheric conditions that are likely to occur. During the whole of the test period, ambient air and tank outside surface temperatures should be observed on an hourly basis.

It is recommended that the boil-off be measured on a total weight basis associated with liquid level and vapour pressure readings. The agitation period may be carried out by distorting the liquid surface level to be representative as far as possible of ship's sea movement. The time period for this test should be as follows.

(a) Cool down rate at about 10°C per hour, i.e. the mean temperature of all the test thermometer readings to drop at a rate of 10°C per hour till the tank is in a position to receive the liquid cargo.

(b) The stabilization period should be at least $1\frac{1}{2}$ days with the liquid cargo at tank testing level. (Not less than 90 per cent of tank volume and not more than 98 per cent of tank volume.)

(c) The undisturbed liquid level test to be conducted over a minimum period of 36 hours.

(d) The disturbed liquid level test to be conducted over a minimum period of 36 hours. The time period used in (c) and (d) should be the same and represent a similar portion of the day and night periods.

(e) The warm up period should normalize the temperature within the insulation. It is expected this would be a 24–36 hour period. Total test time—one week.

Pressure cycling test

Test A The insulated tank with a 90 per cent level at cargo temperature should be subjected to a pressure cycling test.

Total number of cycles	8×10^6
Pressure variation	0–1.75 kg/cm^2
Minimum temperature	Cargo temperature.

The tank should be examined for primary container failure.

Test B The tank is emptied but maintained at cargo temperature by vapour circulation at low pressure and the external wall is subjected to pressure variation as shown in Fig. D4.

Insulation movement measurement

This test is to examine the effect of tank wall movement and the ability of the cargo containment system to tolerate this movement.

If in the pressure cycling test, depending on the tank wall construction to contain the insulation system, the tank wall movement (maximum) is at least five times the amplitude of the maximum panel vibration that is likely to be established by the designed ship's containment system, then the measured results from the pressure cycling test should be used.

It will be seen that by judiciously designing the side panels of the cargo test tank, the above test can also be conducted simultaneously with the pressure cycling test.

Erosion test

The object of this test is to examine the resistance of the insulation primary surface to high velocity of fluid flow at cargo temperatures.

The minimum velocity of flow over the surface should not be less than 18 m/sec. The impending momentum should not be less than 4 m/sec per 1 kg mass. The test may take the

orm of an all-liquid jet impinging on the test surface for a period of 24 hours.

The material should be examined for erosion of the surface, initiation of cracks, collapse of cell structure and loss of mechanical properties.

Material selection and testing

Selected parts of the insulation within the tank should be removed for testing as stated in Section A of this test programme.

Areas of the containment system where materials should be cut out for test purposes are shown in Fig. D5 and correspond to the areas where repair work has to be carried out for Part II. Therefore, both in Part I and Part II of the tank testing programme materials would have to be removed for testing.

PART II

These tests are designed to prove the extent to which the specification used in the design of the insulation system can depart from the set parameters and as to how initiated fault conditions and repairs behave. The tests are similar to that carried out in Part I of this section. (*See* Fig. D6.)

The test tank may be the same as that used in Part I of the test, but with the insulation system modified to demonstrate the following features.

(a) Corner parts of the cargo tank should be reinsulated as repairs. In addition to the corner repairs, repairs should also be carried out on large flat areas as shown in Fig. D5. (These repairs are expected to be equal in or superior to the general insulation system used in the tank containment system.)
One of the anchoring devices should be insulated with a fault condition which illustrates lack of adhesion and fission cracks and surface discontinuity.

(b) The internal surface forming the primary containment system should have the following fault condition. By means of a circular saw of at least 1 mm width a slot should be cut 50 mm in length and to a depth of 10 mm. Fig. D1 shows the types of damaged surfaces that should be investigated.

Test required

The tests stated in Part I of this section should be repeated but reduced in number as follows.

(a) Thermal cycling A One cycle.
B One cycle.
C Six cycles.
D 40 cycles.

(b) Heat leakage test should be repeated in exactly the same manner as stated in Part I of this section.

SECTION C

FULL SCALE TESTS

The purpose of these tests is to establish confidence in the design by demonstrating that a typical corner section of the actual design can be subjected to accelerated testing requirements representative of the ship movements likely to be experienced at sea. (*See* Fig. D7.)

The second part of this model testing is to demonstrate the method of mechanical application of the insulation on the inner hold surfaces and the manner in which quality control and testing would be carried out.

Test requirements such as vibration, torsion and loading tests will be required depending on the proposed design.

It should be possible to establish a torque criteria for these tests which are excessive to that likely to be experienced by the ship in service.

The secondary barrier testing techniques and total insulation failure events should also be demonstrated plus arrangements for pump seats and other anchoring points.

The results of a fracture in the tank hold wall structure should be investigated to determine the effects of:—

(a) Hydrostatic water pressure.

(b) Liquid cargo pressure with the tank empty and full.

APPENDIX 'D'

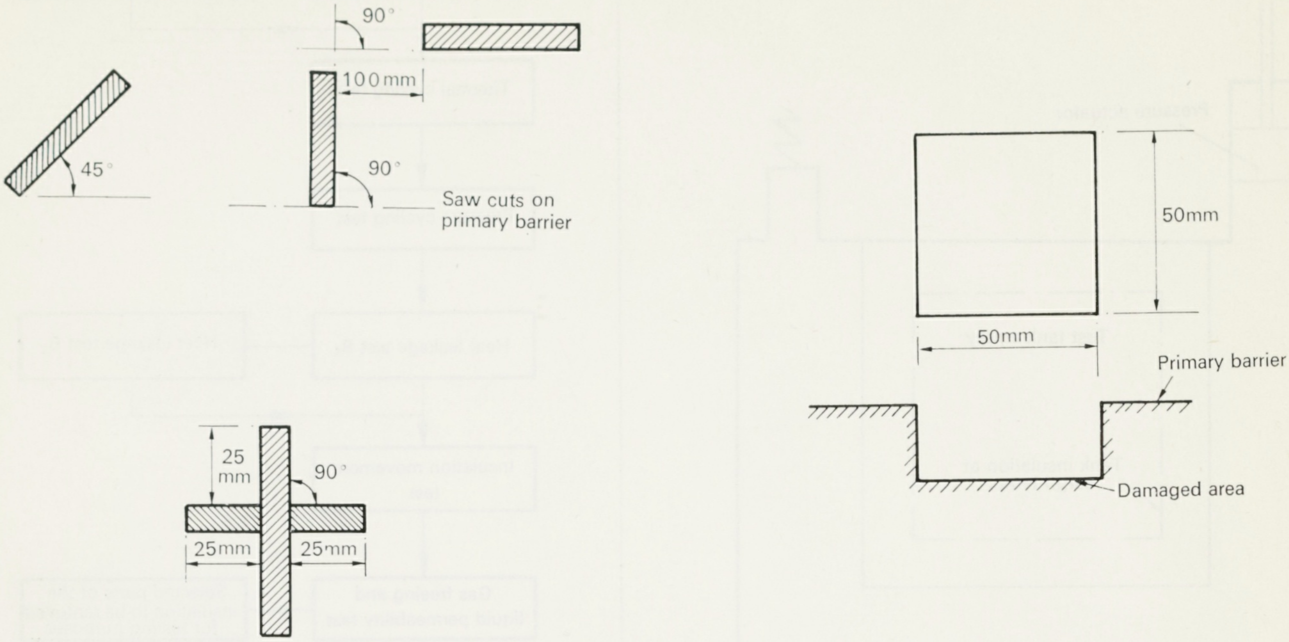


Fig. D1

Saw cut orientation

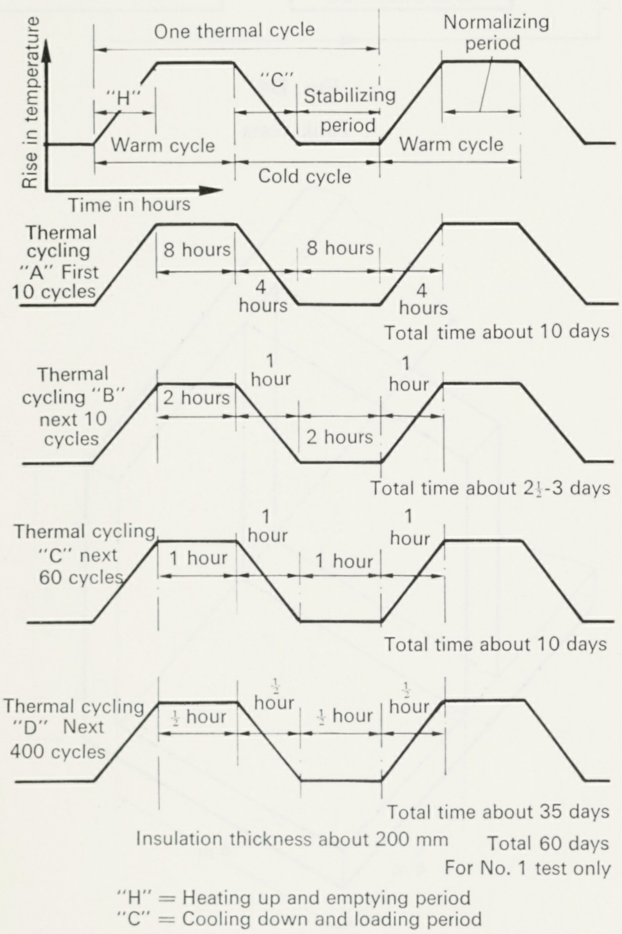


Fig. D2

Thermal cycling test

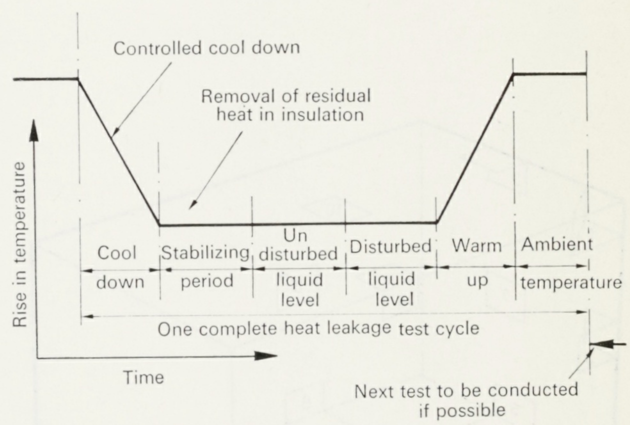


Fig. D3

Heat balance test

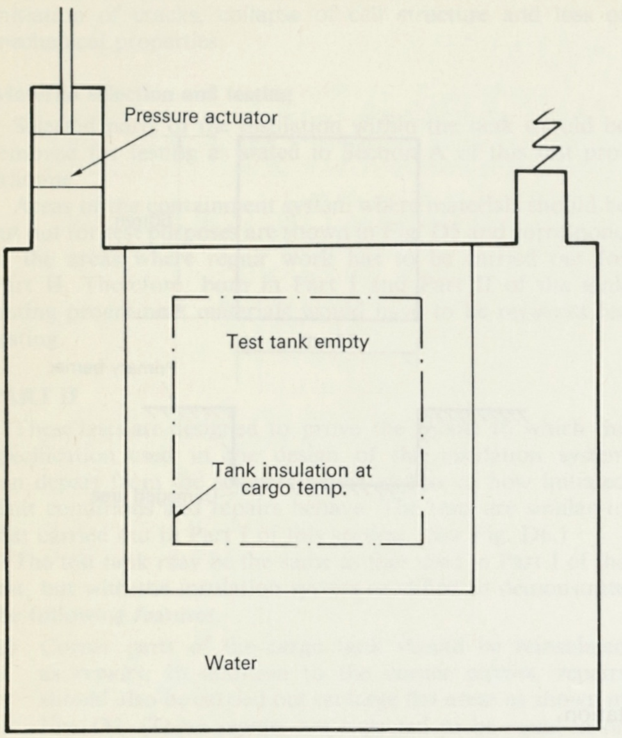


FIG. D4

Pressure cycling test

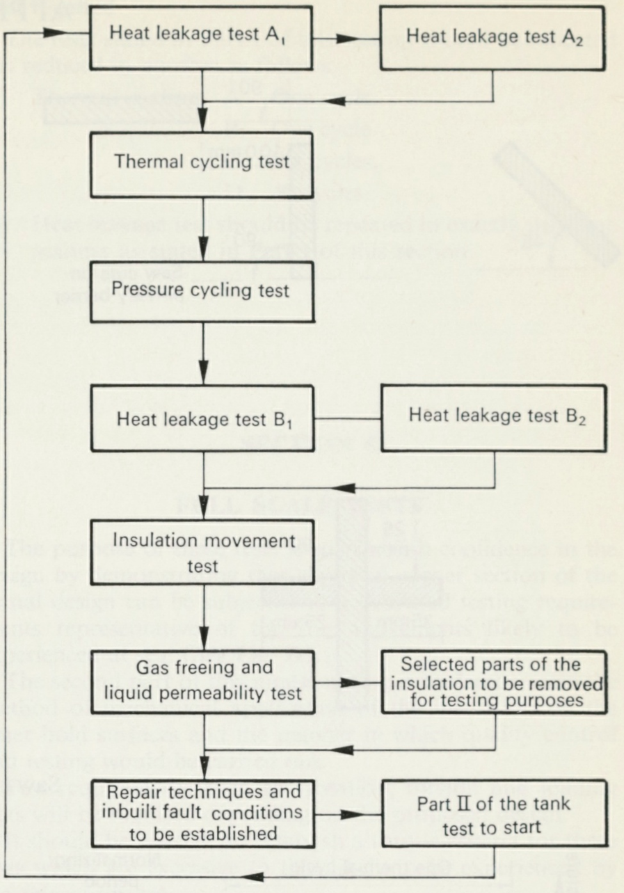


FIG. D6

Tank tests

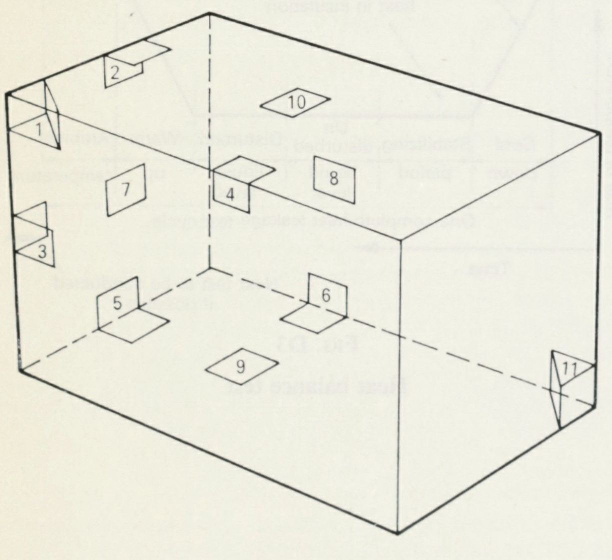


FIG. D5

Material selection for testing

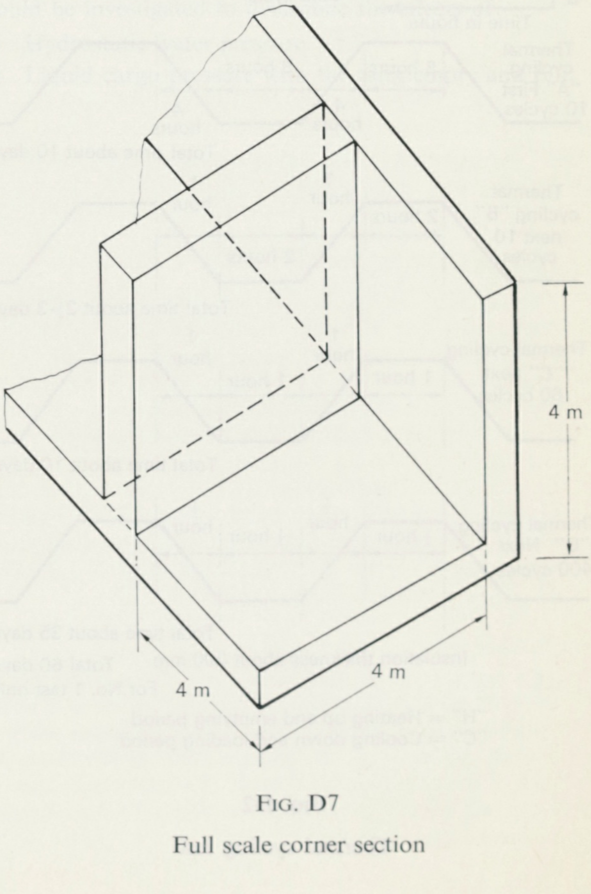


FIG. D7

Full scale corner section

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A. Bell. 7

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FLOATING DOCKS—

Development and Modern Trends

K. C. Thatcher

Paper No. 4. Session 1978-79

FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

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FLOATING DOCKS—DEVELOPMENT AND MODERN TRENDS

by K. C. THATCHER

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1. INTRODUCTION

In the minds of many people floating docks are a product of the twentieth century. This may be true of the floating dock in its present form, but the actual concept has been known for some considerable time. It is intended, in this paper, to outline the development of the floating dock from its earliest beginnings, and to highlight briefly some aspects of modern operational techniques.

2. HISTORY

In order for a ship to be operated in the most economic and safe manner it must be kept in good condition. The propelling machinery, be it mechanical or otherwise, the fittings and the hull must all be kept above a minimum standard of repair. From earliest times, maintenance of the hull has always presented something of a problem since much of the skin, rudder etc. are all immersed, and the ship must therefore be removed from the water to enable these items to be inspected.

Whilst ships were relatively small in size they presented little difficulty for they could be beached at the top of the tide and allowed to dry out. This provided about ten hours in which to carry out the work.

More extensive work could be carried out by raising the ship on a slipway or marine railway, by the use of a graving dock, or by careening. Slipways and docks are, by definition, static installations and it was the search for mobility combined with a means for overcoming the natural limitations of careening which led to the development of the floating dock.

The first use of a floating dock is generally accepted to have been in the time of Peter the Great of Russia (*c*.1700). The master of a naval vessel which was stationed in the Baltic and needed repair, purchased an old hulk named "Camel", removed the interior, fitted a gate at one end, and thereby created the first floating dock.

No doubt this first crude design was improved upon during the following 150 years, but information is distinctly lacking for this period. It was only with the general adoption of iron for ship's hull construction that floating dock technology expanded. Many notable engineering personalities became interested, and we find the next reference to a floating dock in 1846 when Mr. John Scott Russel, of "Great Eastern" fame, addressed the Institution of Naval Architects on "Lenox's Patent Floating Dock". Unfortunately, the exact content of Mr. Russel's address to the I.N.A. was not recorded, and it was not until 1865 that the first recorded paper on floating docks was presented.

The presentation of this paper sparked off a large number of papers and designs, and it is obvious from a study of these old records that whilst some designs were somewhat extreme, the majority were feasible and no doubt adequately fulfilled the basic design requirement of all floating docks viz, to lift a ship clear of the water in order to permit essential maintenance work to be carried out.

The forms adopted were quite modern in appearance, bearing in mind the physical limitations of the materials used; principally cast iron, wrought iron, and timber. Obviously, development was not restricted to the United Kingdom, and a number of European Countries were active in this field. It is somewhat ironic that whilst British dock building has today virtually ceased, the European Yards are still very active. Examples of early dock designs are shown in Fig. 1(a), (b), (c), (d), (e) & (f).

It will be noticed that some of these designs are of unusual configuration. These were no doubt produced to fulfil a particular need, but generally speaking, over the years the design of floating docks has become standardised, and now follows fairly rigid guidelines.

Lloyd's Register has been involved in the classification of floating docks since the early 1960's and has published Rules for docks since 1967. Since the beginning of the Society's involvement more than seventy docks have been designed and/or built to class, and these range from small simple pontoon types to highly sophisticated large capacity docks requiring extensive operational controls.

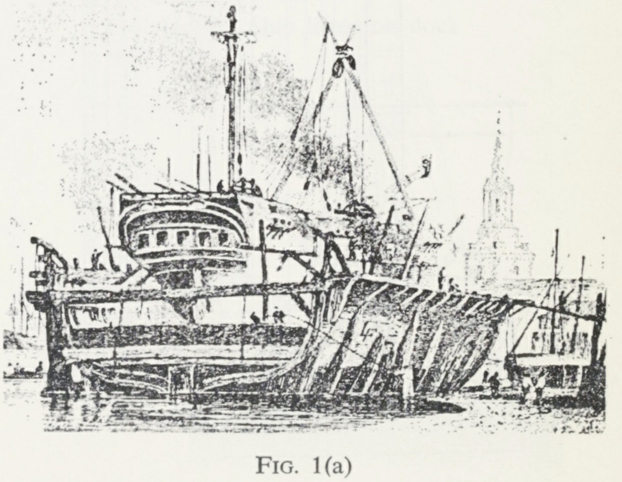


FIG. 1(a)

The old wooden floating dock at Rotherhithe

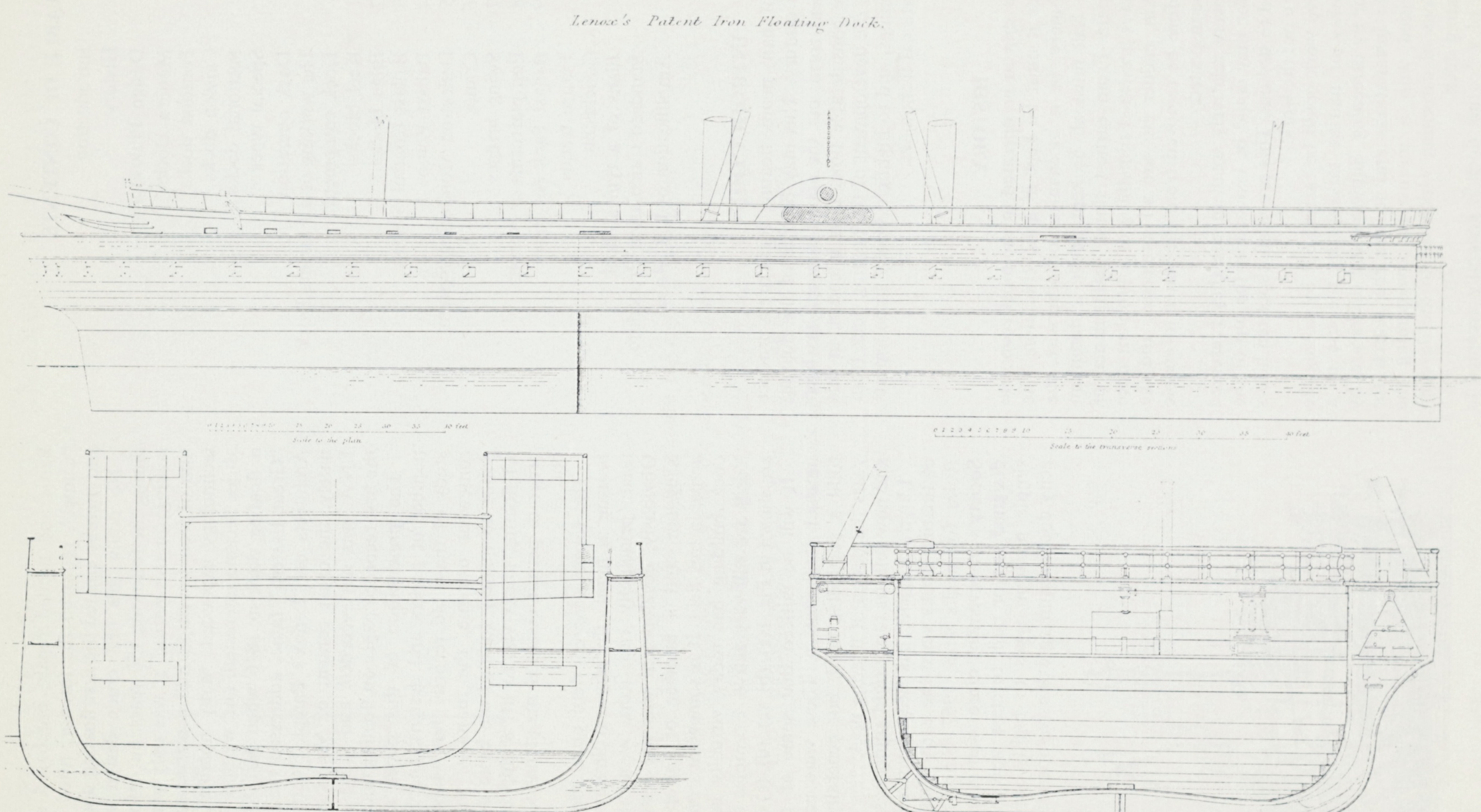


FIG. 1(b)

Lenox's patent iron floating Dock: 1865

Fig. 1(c) Depositing Dock: 1876

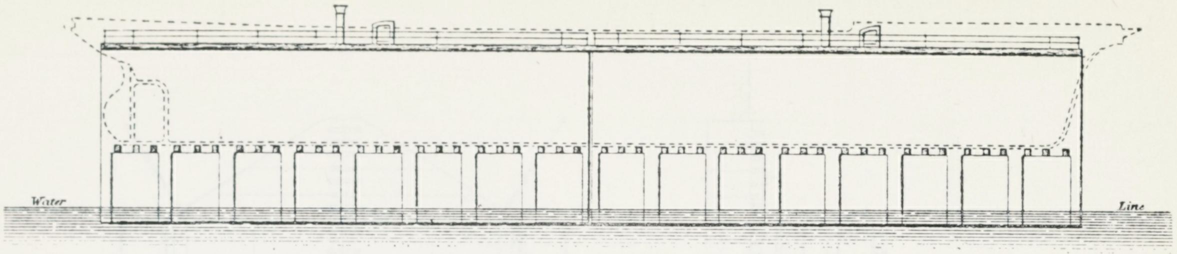


Fig. 1(c) 1 Elevation

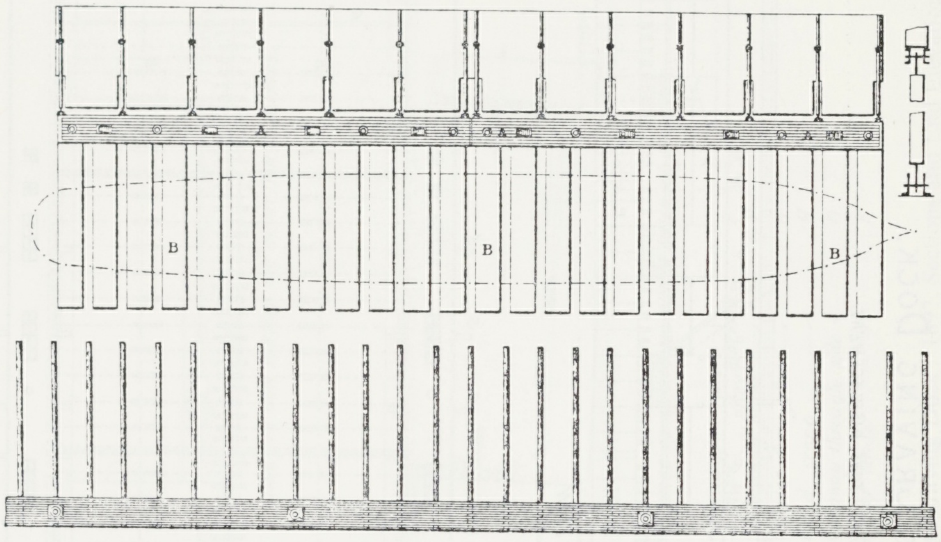


Fig. 1(c) 2 Plan showing dock (above) and depositing grid (below)

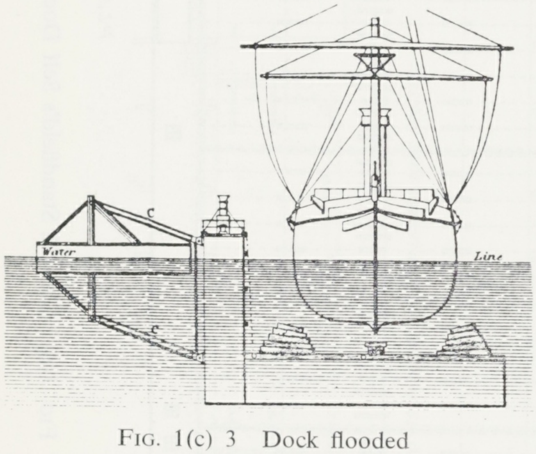


Fig. 1(c) 3 Dock flooded

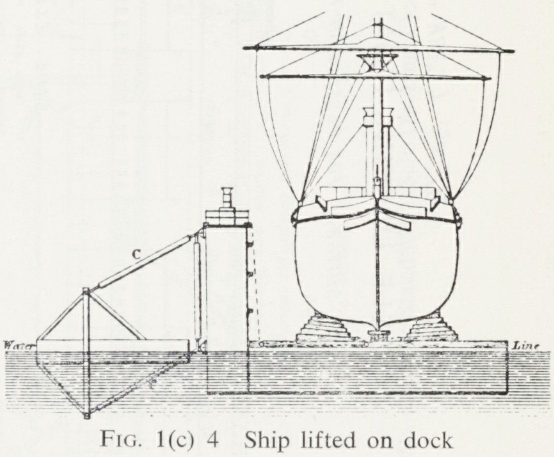


Fig. 1(c) 4 Ship lifted on dock

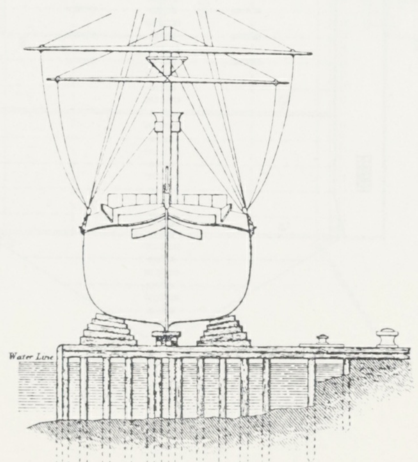


Fig 1(c) 5 Ship deposited on grid

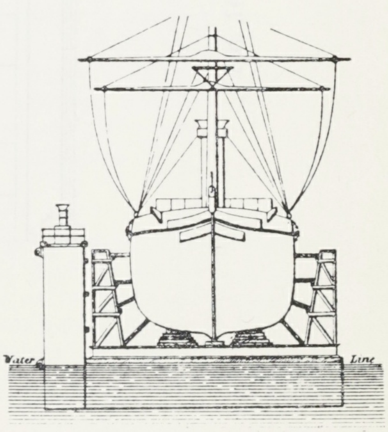


Fig. 1(c) 6 Alternative method of docking with ship kept on dock

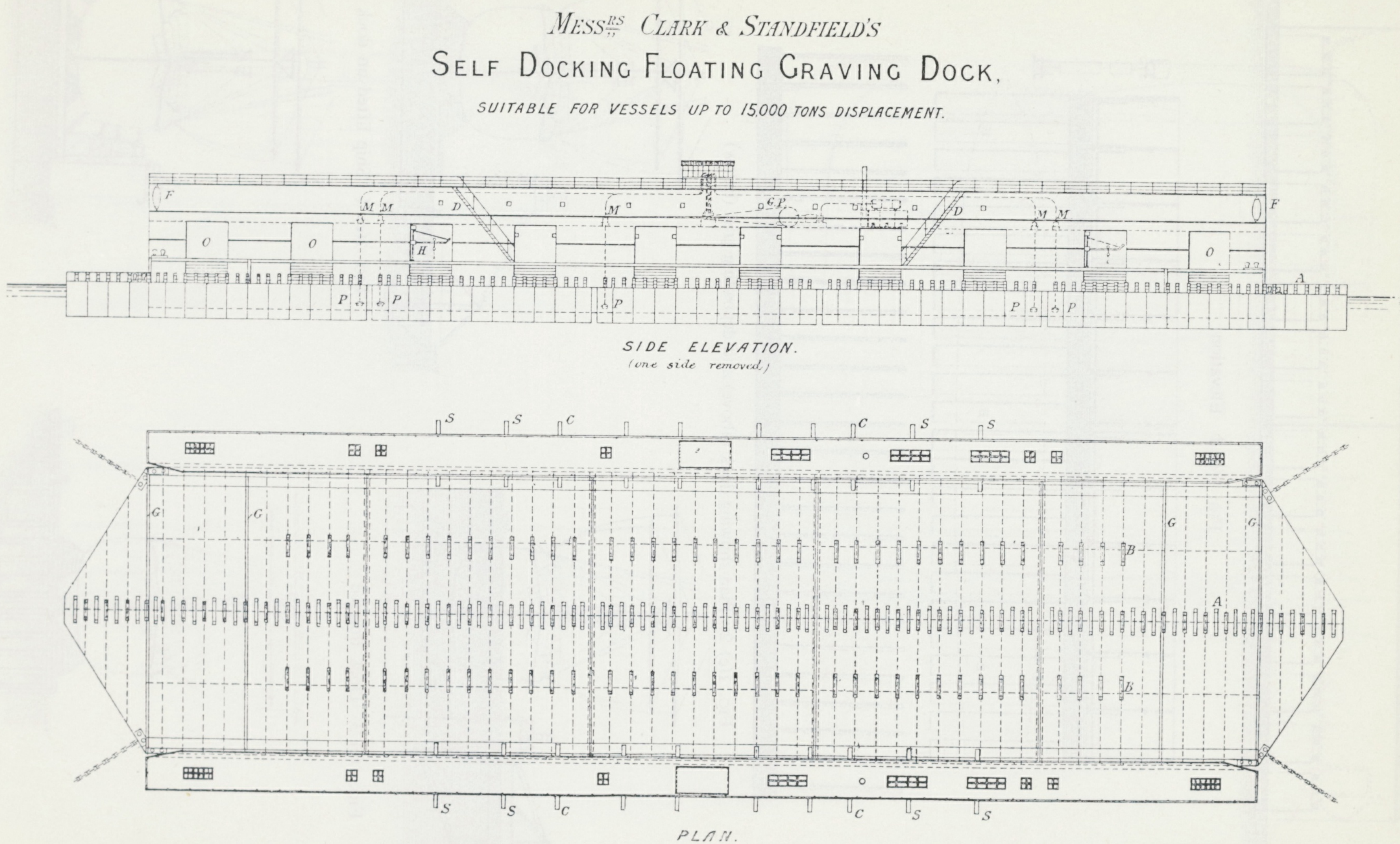
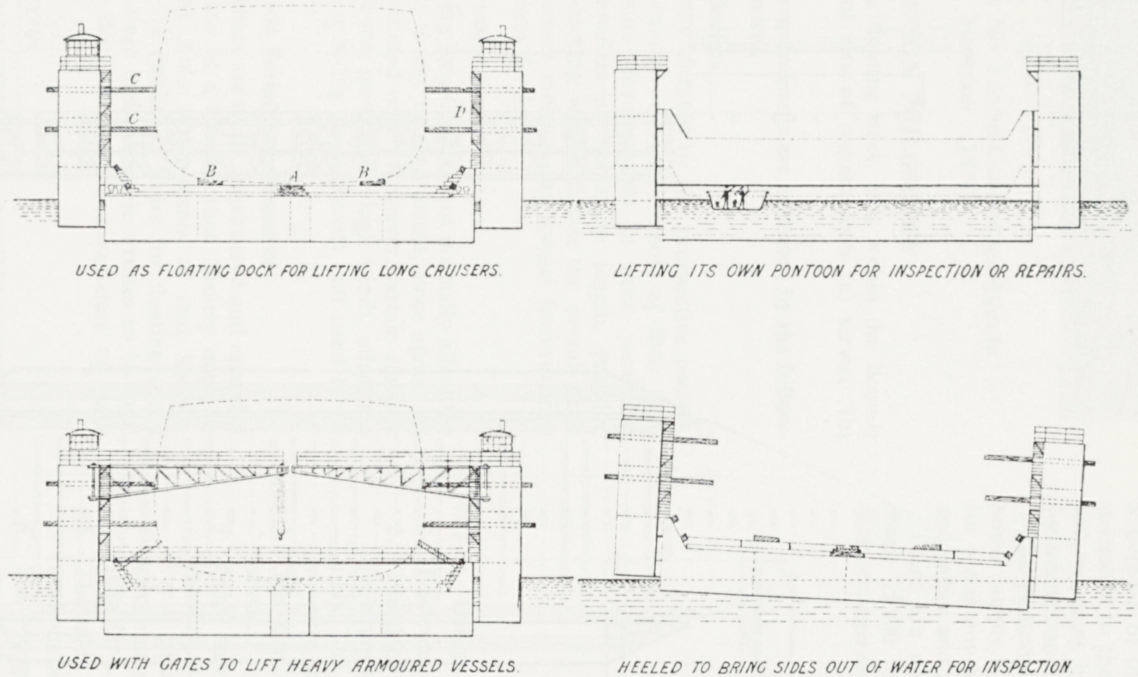


FIG. 1(d) Clark & Standfield's Self Docking Floating Graving Dock: 1897



Note.

Keel blocks ...... marked	*A.*	*Pumps ..... marked*	*P.*
Sliding bilge blocks ...... "	*B.*	*Generating plant ...... "*	*G.P.*
Mechanical side shores ...... "	*C.*	*Grooves for gates ...... "*	*G.*
Mechanical self centring side shores	*S.*	*Hand crane ...... "*	*H.*
Ladders ...... "	*D.*	*Gangway through side "*	*O.*
Electric motors ...... "	*M.*	*Roller fender ...... "*	*F.*

FIG. 1(d) Clark & Standfield's Self Docking Floating Graving Dock: 1897, Sections and End Elevation

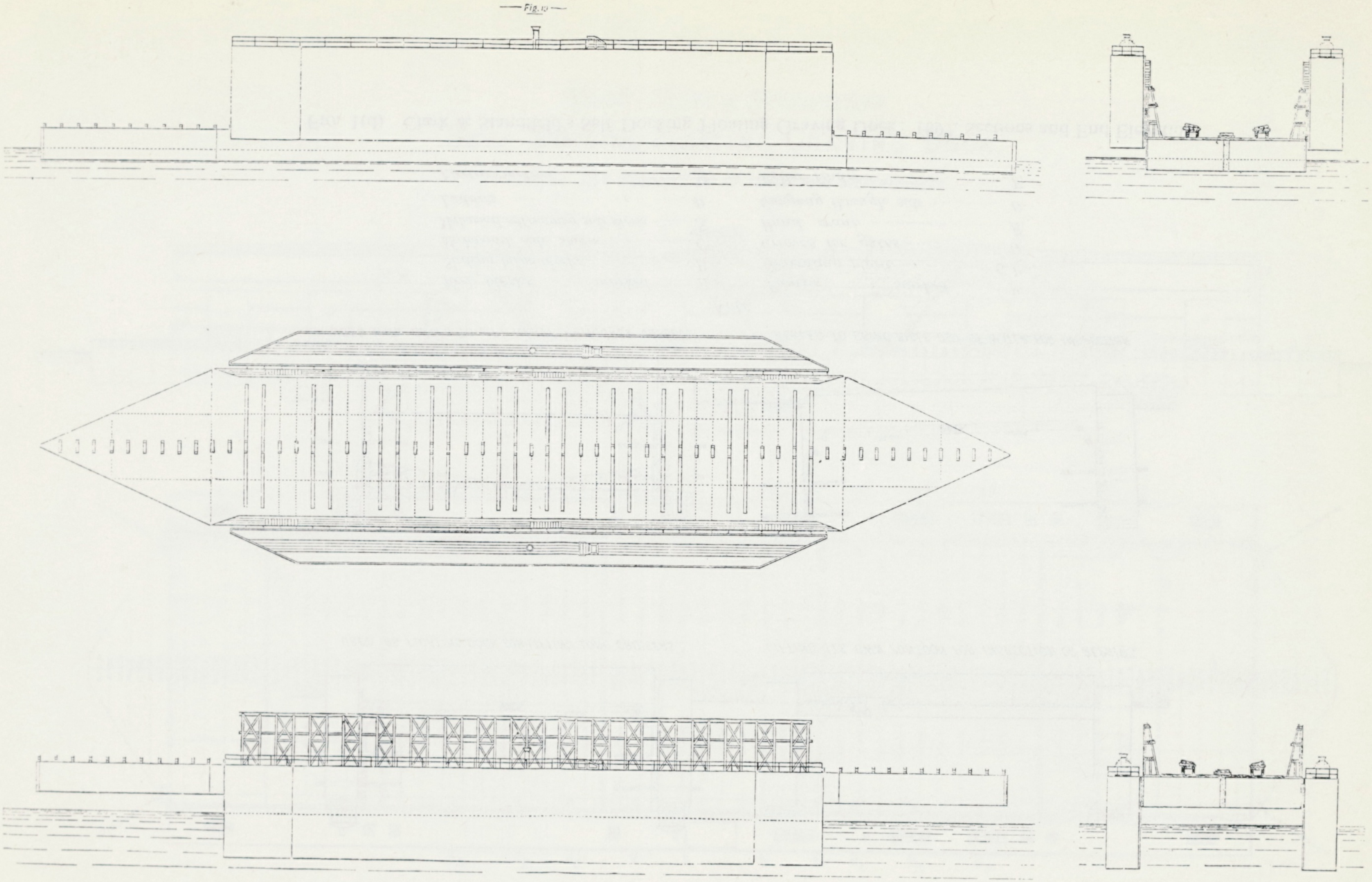


Fig. 1(e)

Latimer Clark's Double Power Floating Dock and Hydraulic Grid: 1879

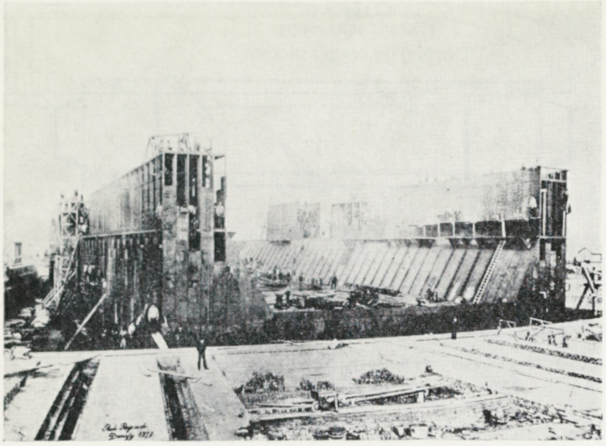


Fig. 1(f)

Floating Dock No. 1 from Gutehoffnungshutte Sterkrade: 1878

3. DESIGN PHILOSOPHY

The design of a floating dock falls within the bounds of two independent sets of requirements (a) service, (b) delivery voyage.

3 . 1 The service requirements are indicated by the following parameters.

3 . 1 . 1 Ship particulars

These are normally dictated by the prospective owners, who will have examined the requirements of their yard and estimated future developments in their particular market. Such particulars as maximum length, breadth, draught and ship docking weight dictate the overall dock dimensions. The owners indicate any special features they require to be built into the design.

3 . 1 . 2 Dock operation location

The dock operating location does not normally affect the design requirements to any marked extent, since almost all docks operate in sheltered water. However, certain climatic and weather conditions, particularly high winds, affect the dock securing and mooring requirements and need to be taken into account.

3 . 1 . 3 Classification Society requirements

Floating docks which are to be constructed and operated under the jurisdiction of a Classification Society must be designed within the Rule requirements of that Society. Lloyd's Register have published Rules for floating docks which give the loadings and allowable stresses to be used when designing a dock within the parameters of para 3 . 1 . 1 above.

3 . 2 Delivery Voyage

If the dock is to be required to undertake an open sea voyage between her port of build and port of service then this must be taken into account when producing the basic design. In particular, the sea conditions which will be met during the voyage must be estimated and the dock structure designed to meet these conditions.

Lloyd's Register estimates the dock strength requirements in relation to the voyage parameters, viz, time of year, duration and route.

4. MODERN DOCKS

The second world war was, for many things, a period of intense development, and floating docks were no exception. Whilst a limited number were produced prior to 1939, the war years saw a great increase in number and type of docks built. During this period dock designs were refined and perfected, and these can be classified broadly into four basic types.

1. Pontoon
2. Caisson or box
3. Sectional
4. Specials

4 . 1 Pontoon Docks

This is probably the oldest of the designs still being built, and consists of two continuous wing walls resting on a number of individual pontoons. The connection of the pontoons to the walls is by bolts or rivets, and in a few isolated cases by welding. The pontoons can be removed for maintenance.

The pontoons are not self contained, in that the main power supply is common to the whole dock, and in order for a pontoon to be dismounted all the pumping controls, and ballast and power lines have to be disconnected.

There are no size limitations, but the largest built is about 25 000 tonnes lifting capacity. The basic pontoon dock arrangement is shown in Fig. 2.

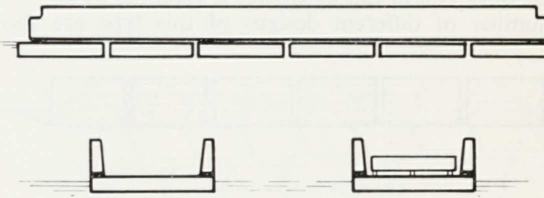


Fig. 2

Pontoon Dock

4 . 1 . 1 Design characteristics

1. Pontoons are generally self docking.
2. The dock capacity may be increased within certain limitations by adding pontoons. (This increases length only. The docking of larger modern wide ships also requires an increase in dock width).
3. The dock is often built in sections and assembled afloat.
4. Since only the wing walls are effective in longitudinal bending, and these are not the full depth of the dock, for a given required section modulus the material thicknesses, and hence dock weight will be greater than for a one piece dock.
5. The dock structure is complex because of the connections between pontoons and wing walls.
6. Sea voyages may be a problem owing to the working of the connection bolts in a seaway. Reinforcement is often required in way of the pontoon gaps to ensure adequate security.

4 . 2 Caisson Docks

As the name suggests, these docks are built in one piece, having a continuous pontoon and two walls i.e. an integral structure. The structure is simpler than for a pontoon type, and scantlings are therefore lighter with a corresponding lowering of dock-weight and hence cost. The majority of docks currently being built are of this type. There are no size limits and the largest dock of this type to Lloyd's Register Class is 55 000 tonnes lifting capacity. The basic Caisson dock arrangement is shown in Fig. 3.

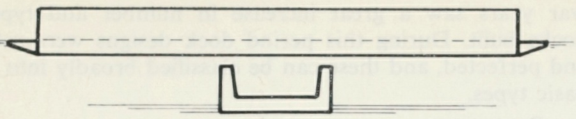


FIG. 3

Caisson or Box Dock

4.2.1 **Design characteristics**

1. Lighter one piece structure makes for simpler design and construction.
2. The material utilisation in this type of dock is more rational.
3. This type is not self-docking. Some means has therefore to be found of examining and maintaining the underwater portion of the dock. This can be achieved by dry docking, careening, or underwater maintenance using divers and/or limpet cofferdams.
4. If the dock is built in sections and joined afloat, underwater welding techniques have to be employed.

4.3 **Sectional Docks**

Any design in which there is no structural continuity over the dock length can be termed a sectional dock.

A number of different designs of this type are shown

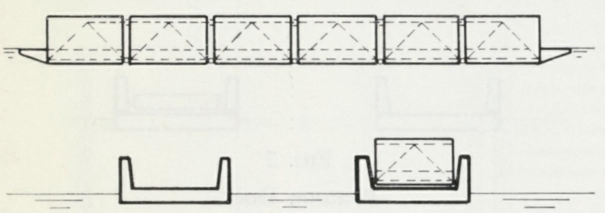


FIG. 4

Trussed Sectional Dock

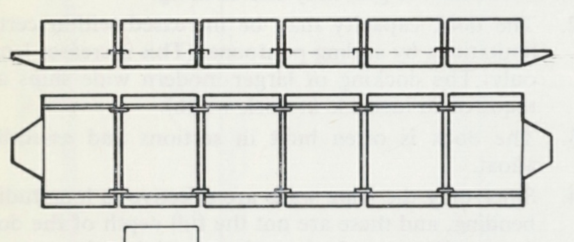


FIG. 5

Loose Sectional Dock

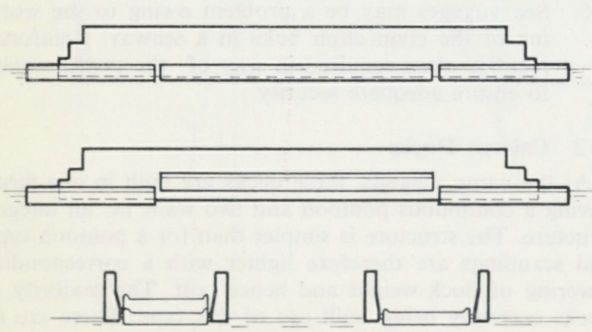


FIG. 6

Lionel Clark Sectional Dock

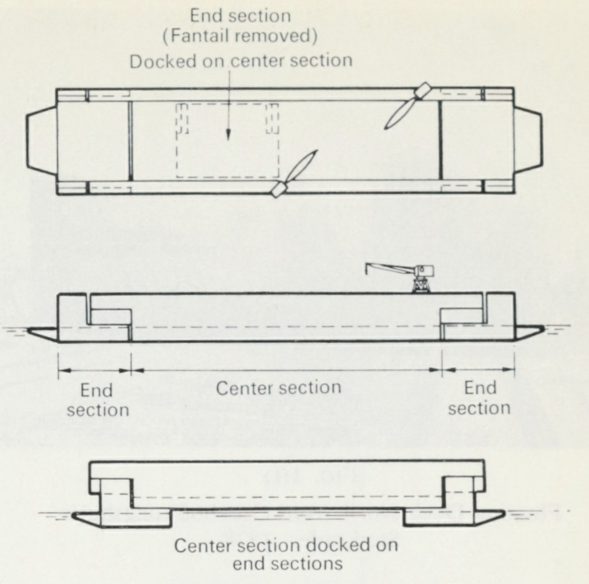


FIG. 7

U.S.N. A.F.D.M. Type Sectional Dock

in Figs. 4 to 7. In each case the design has been developed to permit self-docking of the individual component sections. Each figure shows the dock in its working and docked states.

4.3.1 **Design characteristics**

1. As for pontoon docks except that each pontoon is made completely self sufficient.
2. The longitudinal strength of this type of dock is achieved by means of a system of pin joints and/or tie bars. Problems can arise in the alignment and wear of the pins and in the strength of the tie bars should the dock allowable longitudinal hogging bending moments be exceeded. This type of dock often has different allowable hogging and sagging bending moments with the hogging moment being very much smaller than the sagging moment.

4.4 **Special Types**

Most special types could be said to be covered by the previous heading, but there are a number of docks worthy of mention under the heading of "special".

4.4.1 **U.S. Navy "Advance Repair Dock" (ARD).**

This type was designed during the 1939/45 war as a self contained repair unit capable of being towed to any location in the world. The dock was of ship form for easy towage and had access through a watertight gate at the aft end only. Obviously, the hull form severely limited the size of ship which could be docked, since the vessel could not overhang the ends of the working platform. With a capacity ship the dock floor was actually below the level of the water outside. These docks made excellent military installations since they were completely self contained, having their own power, steam, compressed air, water, workshops and crew's quarters. An outline arrangement of an ARD is shown in Fig. 8.

4.4.2 **Trim Dock**

This type originated from an idea by Messrs. Ankerlokken of Switzerland. It is designed to operate both as a conventional dock for small vessels, and as a means of partially docking larger VLCC's and similar ships. The

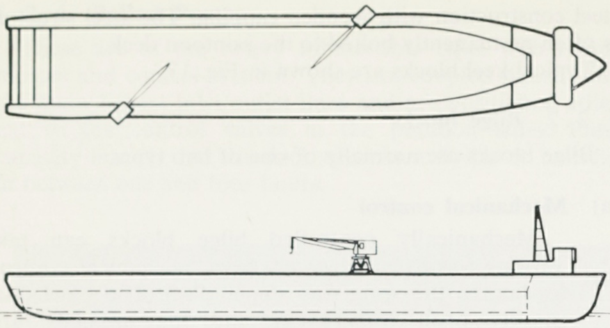


FIG. 8

U.S.N. A.R.D. Type Dock

design configuration, and the methods of operation are shown in Figs. 9 and 10.

A striking feature of this design is the longitudinal assymetry of the hull, in which the four stability towers are arranged with the two forward ones considerably wider apart than the after ones. To date a Trim dock has not been built, although one is being considered for use at Suez.

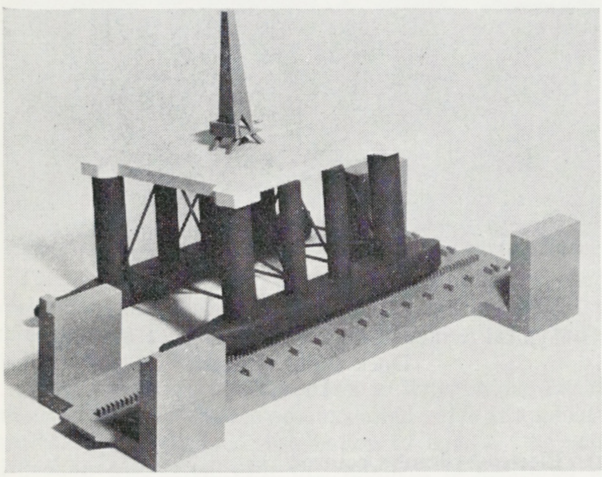


FIG. 9

Trim Dock partially docking Offshore Unit

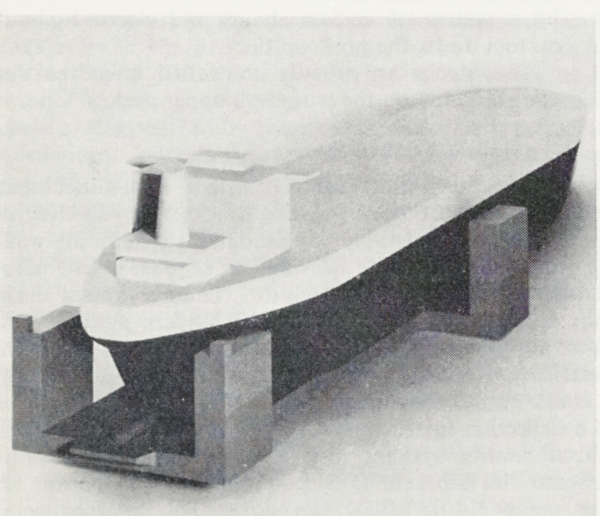


FIG. 10

Trim Dock partially docking V.L.C.C.

4.4.3 C.H. Bailey Sectional Dock

This dock differs from the conventional sectional type in that each unit is completely free and joined to adjacent sections only by means of pinjoints. The dock is a conversion from a U.S. Navy AFDB designed as a self contained wartime repair base transportable anywhere in the world in sections. The pontoons are semi-ship-shaped for easy towing.

The conversion involved the re-orientation of the pontoons and the exclusion of some wing walls.

The pontoons are free to rotate about the pin-joints within a limited arc. The dock relies on the ship for continuity of strength, and design studies carried out by the Society have shown that this will be adequate in most cases.

It is obvious that any work requiring the cutting of the ship (i.e. 'Jumboising') would not be practicable using this design. The dock as converted is intended as a self contained ship repair complex, principally for cleaning and superficial repairs allowing a quick turn-round.

The original and final configurations are shown in Figs. 11 and 12.

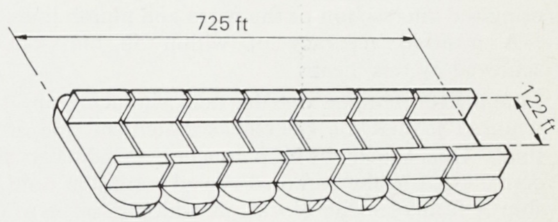


FIG. 11

C.H. Bailey Dock as U.S.N. A.F.D.B.

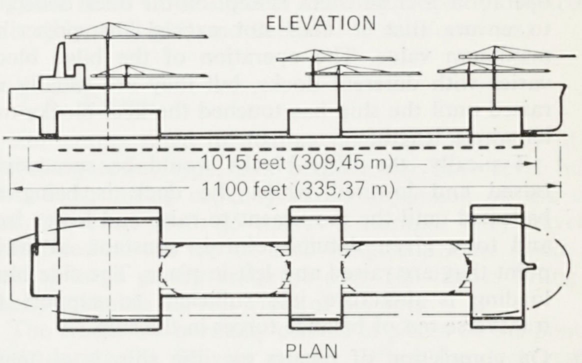


FIG. 12

C.H. Bailey Dock as finally envisaged

5. DOCK OPERATION

5.1 The Working of a Floating Dock

One major difference between a floating dock and any other form of ship lifting system is the fact that the dock is free floating and is in no way attached to the land (except to hold it on station). This means that the hydrodynamics of the dock form play an important part in the dock operation, and can limit the dock's use.

A standard docking procedure would be as follows:

(i) Assess the vessel to be docked by ascertaining whether damage, excess cargo or hull weight, excessive trim

or heel, or any other defect prevents satisfactory docking (this would be common to all types of ship lifting systems).

(ii) Prepare the dock for operation, adjusting the position of the keel blocks and/or side blocks as necessary by reference to the ship's docking plan.

(iii) Flood the dock to some pre-determined draught over the keel blocks such that the vessel can enter with a reasonable margin of safety.

(iv) Bring in the ship. Initially the ship is brought to the dock location by tugs, and, if this dock location permits, the tugs then draw the ship into the dock by passing straight through.

In the majority of cases the dock location does not permit access through the landward end and the ship will be drawn into the dock by means of cables taken to windlasses on the dock walls.

At least four cables are used, two aft and two forward, so enabling the ship to be kept under control at all times. The positioning of the ship is often achieved by eye using a wire stretched tightly across the dock at a pre-determined longitudinal position on which is marked the dock centreline and graduations either side thereof.

The ship has plumb lines attached fore and aft on the centreline and positioning is carried out by eye using the intersection of the wires and plumb lines.

A position accuracy of within 50 mm can be achieved by this means.

(v) Commence pumping out the dock, inducing any trim required so that the keelblocks match the line of the ship's keel. When the ship touches, the dock is then de-ballasted in the trimmed/heeled condition until the ship is firmly on the blocks, at which point it will be levelled out. The final pumping up is carried out by gradually bringing each end up a little at a time until the pontoon deck breaks the surface. The practice of raising one end eases the water flow and has a stability advantage. During the whole pumping up operation, a close check is kept on the dock deflection to ensure that it does not exceed the prescribed maximum value. The operation of the bilge blocks varies with different docks, but they are usually not raised until the ship has touched the keel blocks over its whole length.

Typically, the bilge blocks would be successively raised and lowered whilst the dock is being de-ballasted until the movement to raise and lower from and to a given datum point is constant, at which point they are raised and left in place. The side block loading is therefore just sufficient to support the transverse out of balance forces in the ship.

(vi) On completion of repairs etc. the ship is re-floated by a reversal of the docking operation.

Dock operators obviously prefer to keep a standard block arrangement capable of supporting the majority of ships, since any alteration thereto necessitates at least one additional de-ballasting/flooding operation which is time consuming and costly.

5.2 Dock Equipment

Under this heading falls every conceivable item contained within the dock structure. It is proposed, however, to restrict reference to major items only, and these will be principally items peculiar to floating docks.

5.2.1 Keel Blocks

Keel blocks are not significantly different from those used in other types of dock. They are usually of fabricated steel construction with wooden capping. The steel structure is often permanently bolted to the pontoon deck.

Typical keel blocks are shown in Fig. 13.

5.2.2 Bilge blocks

Bilge blocks are normally of one of two types:

(a) **Mechanical control**

Mechanically controlled bilge blocks can take various forms but they all have mechanical controls leading to the wing wall upper deck. The blocks are usually fixed transversely and longitudinally and moved only in the vertical direction.

If fixed, they are sufficiently wide to cover a satisfactory range of vessel widths. They are controlled from the top of the wing walls. See Fig. 13.

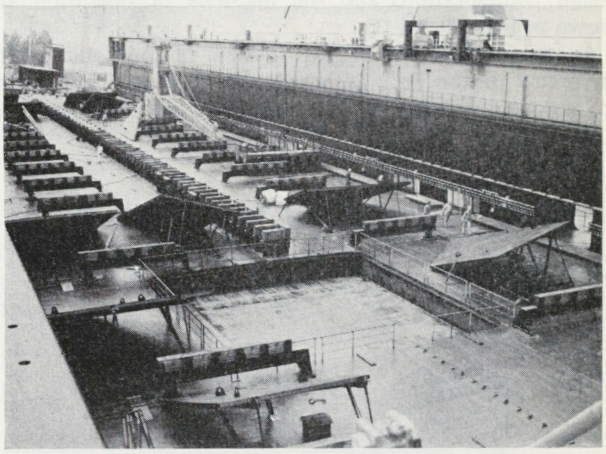


FIG. 13

Typical Arrangement of Keel and Bilge Blocks on Dock Pontoon Deck

(b) **Electro-hydraulic control.**

Electro-hydraulic controlled bilge blocks are normally smaller than the fixed mechanically controlled type. They are movable transversely, and often vertically, on fixed guides. The movement is achieved by a system of endless chains and electro-hydraulic motors under the pontoon deck.

The blocks are usually controlled from the dock control house on the wing wall upper deck.

5.2.3 Ballast Control System

An elaborate ballast control system is a fundamental design feature of most floating docks. Lloyd's Register Rules gives considerable longitudinal strength allowance for docks in which the distribution of ballast can be accurately maintained to reduce the bending stresses during ship docking operations. A typical modern system would have all pumps and tank distribution valves controlled electrically from the dock control house on the wing wall. A check on the dock longitudinal bending is kept by the use of a deflection metering system (see para. 5.2.5). Modern ballast control systems also incorporate interconnections between the separate tank pumping lines to permit any one pump to de-ballast the dock. The interconnection valves are operated manually from positions on the safety deck. A typical view inside the safety deck is shown in Fig. 14.

5.2.4 **Ballast Pumps**

These are of the rotary submersible type, with remote motors and control systems. They are coupled directly into the main ballast inlet/outlet lines and are positioned adjacent to the control valves in the pontoon sides. Pump capacity is such that the dock can normally be de-ballasted in between one and four hours.

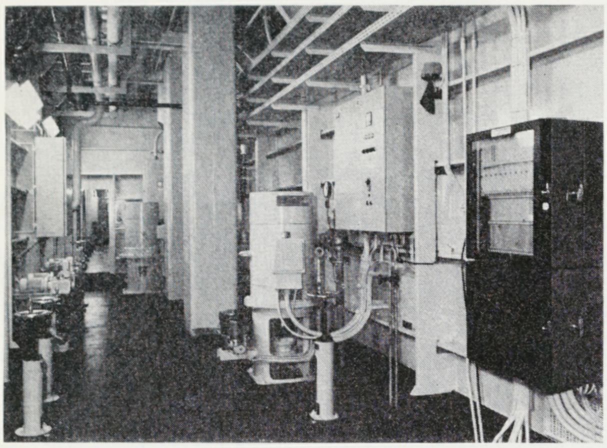


FIG. 14

Typical View along Safety Deck space

5.2.5 **Deflection Monitoring System**

In common with any other fabricated structure, a floating dock is designed to maximum stresses which must not be exceeded in service.

The longitudinal bending stress is contained within its allowable value during the docking of a ship by the constant monitoring of the dock deflection using built-in deflection monitoring systems.

At the dock acceptance trials a longitudinal bending moment equal to the maximum design value is applied by means of a pre-defined distribution of ballast. The actual deflection associated with this moment is measured and used to calibrate the deflection monitoring systems. This deflection is also the maximum which may be accepted in service.

In practice the service allowable deflection is often fixed at a proportion of the maximum value obtained at the sinkage trials, the proportion usually being from one half to two thirds. Deflection monitoring systems can be hydraulic, electrical, or optical, or a combination thereof. Lloyd's Register Rules require at least two completely independent systems to be fitted to each dock classed and this requirement is normally fulfilled by fitting one automatic system, either hydraulic or electrical, and one optical system.

Hydraulic systems work on the principle of a manometer 'U' tube, and have the reading for various points along the dock conveniently arranged in the control house.

Electrical systems often take the form of strain gauges fitted to the dock bottom and/or deck plating at points along the length. The strain differences are indicated on meters in the control house.

The optical system works on the principle of the theodolite with the telescope(s) positioned in the control house and the gauge scales at the extremities of the wing walls.

Lloyd's Register Rules require that on large docks (above 40 000 tonne lifting capacity) each deflection monitoring system must give an audible warning when the deflection approaches the maximum service value and the pumps must automatically stop before the absolute maximum deflection is reached. A typical hydraulic system read out unit is shown in Fig. 15.

FIG. 15

Typical Dock Control Panel Showing Deflection Metres (Upper Right) and Ballast Control Equipment

5.2.6 **Cranes**

The cranes fitted to floating docks are normally of the travelling tower type, and occasionally have level luffing jibs. Their lifting capacity varies depending on the dock size, however, 10 to 25 tonnes is normal. They travel on rails fitted on the top of each wingwall. Some docks also have a large gantry crane of over 100 tonnes lifting capacity spanning the full width of the dock.

The cranes are normally carried in pieces on the pontoon deck during the delivery voyage. When the dock reaches her service port, they are assembled and lifted into position on the wall. (See Fig. 16).

5.2.7 **Swing Bridges**

The swing bridges are fitted at the aft end (i.e. the end furthest from the entrance) of the dock and provide access between the two wingwalls without descending to the pontoon deck. They are the only means of crossing when the dock is flooded. (See Fig. 16).

5.2.8 **End Platforms or Aprons**

These are removable continuations to the pontoon deck fitted at each end of the dock to extend the working platform. They do not take any keelblock loadings, but are

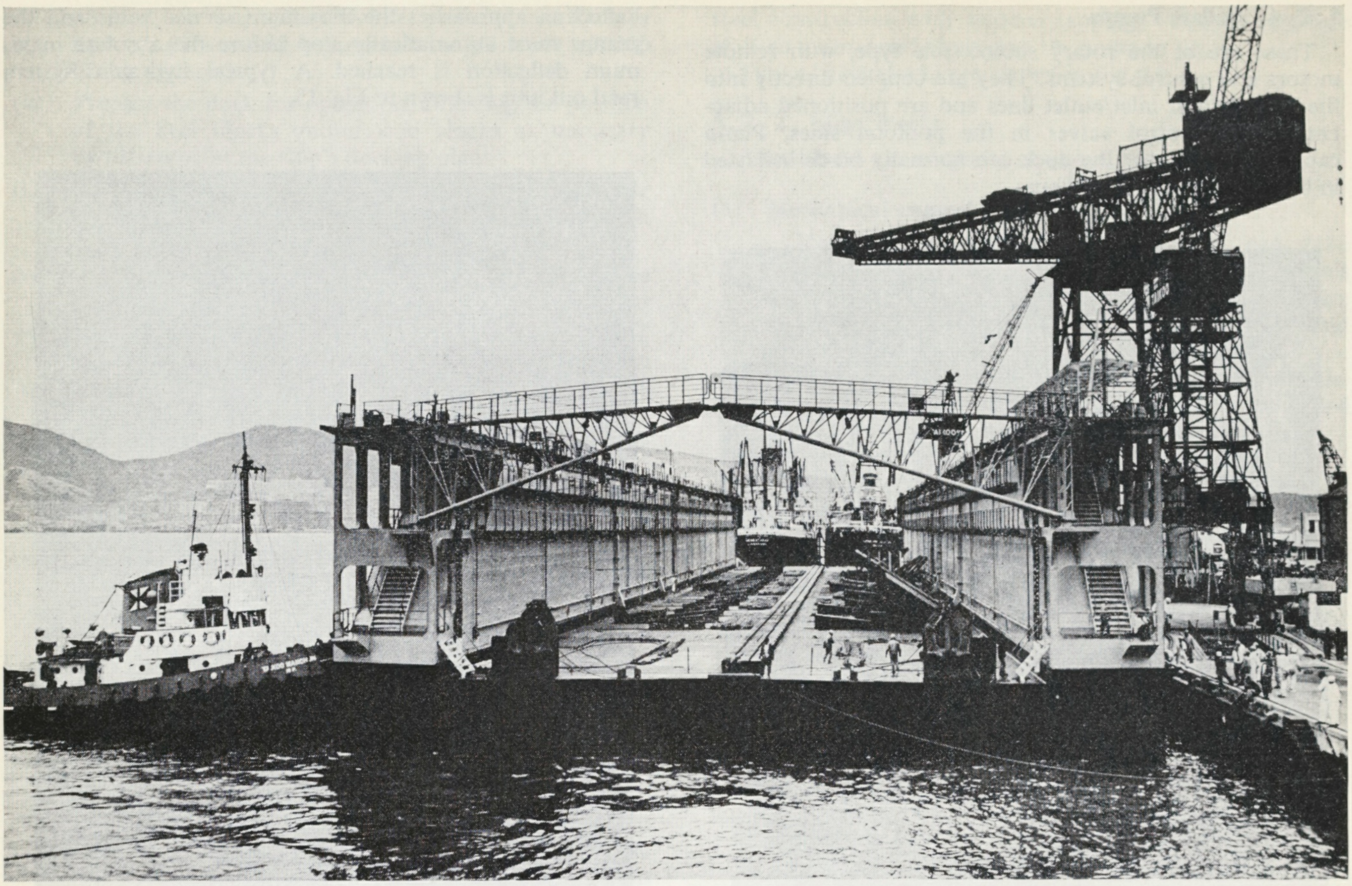


FIG. 16

End view on Dock showing Crane Being Lifted into position on wing walls and swing bridges

often designed to accept the weight of substantial items of equipment and the movement of wheeled vehicles.

5.2.9 **Ballast Tank Air Pipes**

The ballast tank air pipes serve two purposes:

(i) to allow air to escape from the tanks when being filled.

(ii) to restrict the amount of ballast in the tanks so that the dock will float at the design waterline with all the valves open.

Requirement (i) is common to all tanks and needs no elaboration here.

Requirement (ii), however, is critical for a floating dock since the unlimited ingress of ballast into the tanks would undoubtedly result in the complete submergence of the dock. It should be noted at this point that most docks are designed with overcapacity ballast tanks to compensate for variations in final dock weight and to permit differential ballasting of the dock.

The ballast is limited by extending the airpipes into the tanks, to a pre-determined distance below the deckhead, thereby creating air spaces when the tanks are full. In practice, the air pipe length below the deckhead is initially adjustable within limits to enable the free floating draught to be accurately positioned during the sinkage trials.

6. FUTURE TRENDS

If the past ten years can be considered indicative, then the future of the floating dock is certainly assured. The cheapness of construction and maintenance, and speed of operation, when compared with a graving dock, has attracted many ship repairers to the floating dock, resulting in a marked upsurge in dock building.

In one respect, however, the future will not see any marked increase; namely dock lifting capacity. The majority of docks built are in the range 10 000 to 35 000 tonnes lifting capacity, and, with one or two possible exceptions, it is not envisaged that the upper limit of this range will be markedly increased. In fact, with the era of the ULCC effectively over, it is highly probable that dock size will reflect the smaller sizes of ships now being built and in future lifting capacities are not likely to exceed 20 000 tonnes.

Whilst the standard type of floating dock can be considered to have evolved almost to its ultimate, it can be expected that new configurations and designs will evolve from particular sets of circumstances, and to fulfill a particular need. Also, new materials will be employed since although most types of construction have been tried in the past, modern technology can drastically alter the way in which a material is used. In particular, pre-stressed and post-tensioned concrete is currently being tried, and whilst the high weight of this material when compared with steel can be a disadvantage, the ease with which concrete can be used by a comparatively unskilled labour force makes it very attractive to developing countries. Ferro-Cement, in which a substantial steel armature is impregnated with a cement mortar, is another material which has possibilities in dock construction, although to my knowledge it has not been used so far.

The future will also see more sophisticated control equipment, with computers, possibly coupled directly to

the ballast level indicators, providing much of the data required when flooding and ballasting. This is particularly true for the larger docks and those of unusual construction or design, where any error in ballasting resulting in excessive deflection would be disastrous.

7. CONCLUSION

The modern floating dock has been developed over a considerable length of time. Its design philosophy is well understood and can be adapted to suit particular environmental and service conditions, thereby giving a flexibility of use unobtainable with any other type of docking installation. Lloyds Register has been at the forefront of development and will continue to remain so, thereby playing no small part in ensuring a healthy future for the floating dock.

ACKNOWLEDGEMENTS

The Author wishes to thank the many colleagues and friends in UK and abroad who supported and contributed in the preparation of this paper. In particular, Mr. K. Bischoff of Messrs. Gutehoffnungshutte, for his assistance in supplying photographs and illustrations, Mr. A. Bruce of Hamburg, for his unstinting efforts on my behalf in obtaining much useful information, and Mr. G. Pumphrey for the excellent illustrations.

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APPENDIX I

A TYPICAL FLOATING DOCK

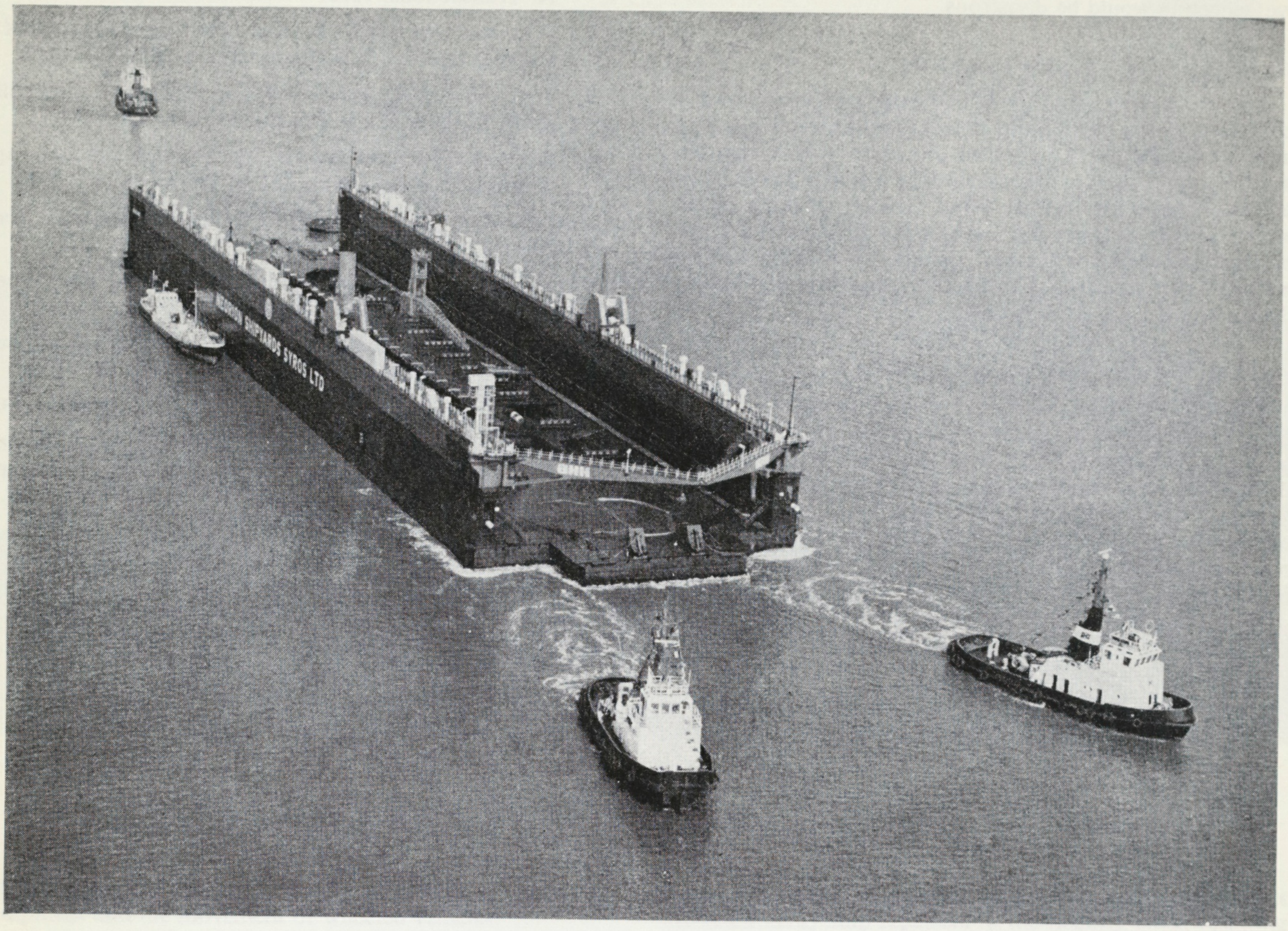

Fig. I.1
Dock at commencement of Delivery Voyage

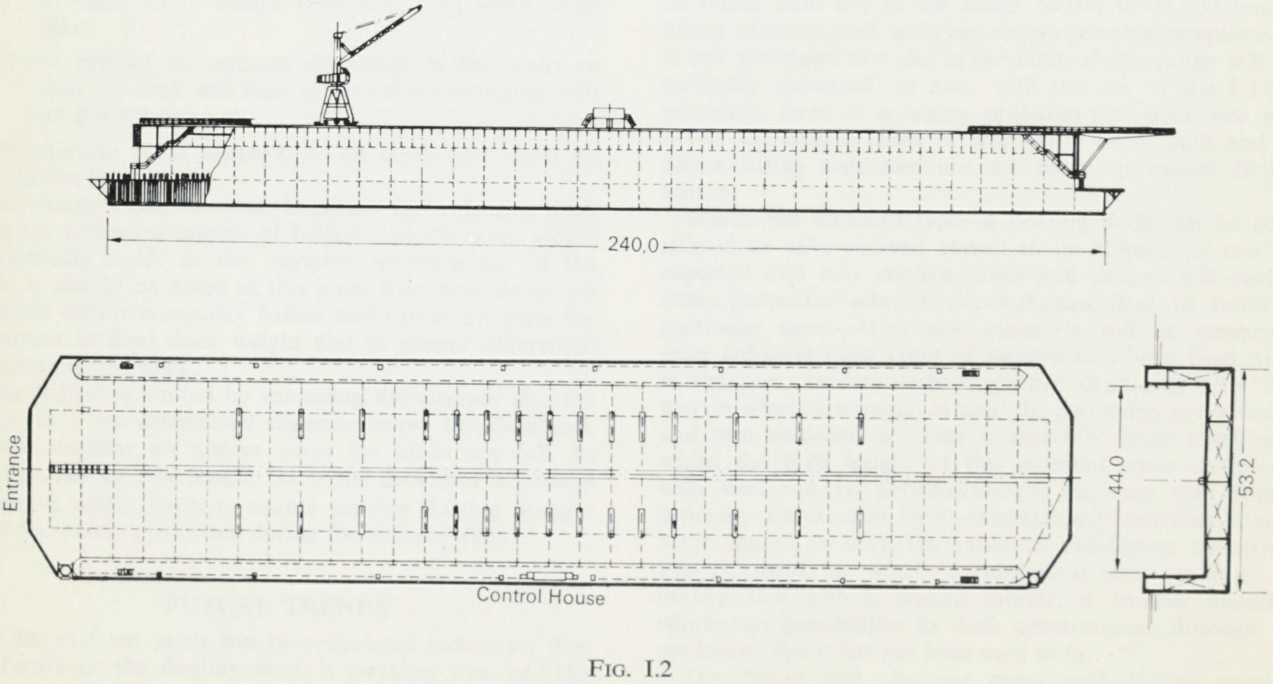

Fig. I.2
Arrangement of typical modern Dock

APPENDIX II

STANDARD CALCULATION PROCEDURE

1. LONGITUDINAL STRENGTH

The longitudinal strength of a floating dock is based on two independent requirements, (i) the ability to withstand longitudinal bending from ships being docked. (Service condition) and (ii) the ability to withstand bending moments imposed by waves during the delivery voyage, where this is applicable.

(i) Service Condition

The minimum Section Modulus (Z) required by the Society's Rules for the dock transverse section at mid-length for the service condition is derived by analysing the longitudinal bending moments present in the dock when supporting a ship of maximum lifting capacity (L.C.) and with the weight represented by a standard distribution.

The distribution used takes the form of a rectangle of length L_S and area 2/3 × L.C. upon which is superimposed a parabola of length L_S and area 1/3 L.C.

The centre ordinate of this distribution can be shown to be equal to:—

$$\frac{1.167 \times L.C.}{L_S}$$

Ship length L_S, is taken as 0.8 of the Dock Length (L_D) for docks up to and including 44 000 tonnes lifting capacity. Thereafter it successively increased to 0.92 L_D at 70 000 tonnes lifting capacity. (See para D307 of Rules).

When calculating the bending moment the dock is assumed to be free of ballast, except restwater. If the position of the travelling cranes is not specified, they are placed at mid length. Evaluation of influence line characteristics need not be carried out except in special cases. The required minimum section modulus resulting from this bending moment is given by

$$Z = \frac{L.C \times 12500}{f} (L_D - 0.917\ L_s)$$

(See D.307 of Rules).

The value of f is taken as either 2200 kg/cm^2 or 1400 kg/cm^2 depending on whether the dock is to be operated with, or without, differential ballast control, respectively.

The higher permissible design stress of 2200 kg/cm^2 is allowed when the dock is fitted with an efficient differential ballasting system and is accepted since such a system reduces the Still Water Bending Moment (S.W.B.M.) during the docking operation. The actual maximum stress in the working condition, regardless of whether a differential ballast control system is fitted or not, is 1400 kg/cm^2. The value of f = 2200 kg/cm^2 is only used when calculating the Rule section modulus.

When a differential ballast control system is fitted there must be a sufficient reserve of tank capacity to permit the required ballast distribution whilst still maintaining the full lifting capacity.

(ii) Delivery Voyage Condition

When a dock has to undertake an open sea voyage from its place of build to port of service, account of this voyage must be made when deriving the dock longitudinal strength requirements.

The methods employed by Lloyd's Register are defined in the following paragraphs, together with a curve of bending moment against a numeral derived from a detailed examination of all previous voyages. All the methods employed require the following data to be submitted by the designers.

(a) Time of year in which voyage will take place.

(b) Duration of voyage.

(c) Route taken.

The wave period associated with a wave length of L_D, is calculated from the dock dimensions. Using this information and the data contained in "Ocean Wave Statistics", (Hogben & Lumb, H.M.S.O.), the significant wave height associated with the particular voyage is derived. This wave height is then used in one of the following methods to produce a wave bending moment, and hence a minimum required section modulus for the dock. In these calculations it is normally assumed that the S.W.B.M. for the dock approximates to zero. If this is not the case, then the S.W.B.M. must be added algebraically to the hogging and sagging wave bending moments before deriving the minimum section modulus required. For the delivery voyage condition the allowable stress is 1730 kg/cm^2.

(ii) . 1 Method 1: Wave Probability Ratio Method

This method utilises the standard wave bending moment derived from Lloyd's Register Rules for steel ships (Part 3, Chapter 4, para. 5 . 3 . 1 in the 1978 Rules), and conversion factors dependent on the voyage duration, sea areas, and time of year are applied. It is known that this method tends to over-estimate the wave bending moments in comparison with other methods. It has the following characteristics:

— takes account of voyage duration.

— relatively simple calculation.

— does not, however, differentiate between dock and ship of the same dimensions.

— does not take account of dock weight.

(ii) . 2 Method 2: Wave Height Ratio Method

This method utilises a factor derived from a comparison of the maximum estimated voyage wave height with that determined for all seasons North Atlantic, the waves having the same length and period. The factor is entered onto an empirical curve derived from an analysis of towage wave bending moment data, from which a bending moment correction factor is obtained. This bending moment correction factor is applied to the ship Rule wave bending moment as derived in 2 . 1 above.

This method has the following characteristics.

— developed to reflect selected sea route and seasons.

— does not take into account the precise duration of the voyage apart from broad selection of seasons.

— does not take account of the dock weight.

The results obtained by the application of this method tend to represent the mean of bending moment estimates derived from the application of other methods.

(ii) . 3 Method 3: Static Balance Method

Whilst both the preceding methods are related to Rule requirements for wave bending moments for conventional ships, this method utilises the static balancing of the dock

on a wave crest or trough. Since a sine wave form is used to represent the sea wave, the moments derived for both the hogging and the sagging case are the same. If a trochoidal wave form was used there would be about 2% difference between the two cases and it is felt the inaccuracies present in the method of estimating the wave height do not justify the extra work involved when dealing with the trochoid. The method uses a group of curves derived from standard sine wave theory from which the relative positions of the centres of buoyancy and gravity of the dock are calculated. These enable the mid-dock bending moment to be derived.

This method has the following characteristics:

- takes account of the dock weight.
- does not take account of the precise voyage duration other than season selection.
- assumes a sinusoidal wave form.
- does not take into account the Smith effect.
- is based on static theory with no allowance for dynamic factors.

(ii) . 4 **Standard Numeral**

From an analysis of the preceding methods, which have been used on previous dock voyages, a curve was produced in which a standard numeral is plotted against the voyage wave bending moment for each dock (M_W).

The numeral employed is:—

$$N = L_D^2\, B\, C_1\, H_{\frac{1}{20}}$$

where L_D = Dock length

B = Dock breadth

C_1 = Factor taken from table 4 . 5 . 1, part 3, Rules for Steel Ships.

$H_{\frac{1}{20}}$ = significant wave height as derived from wave statistics.

The curve is shown in Fig. II.1.

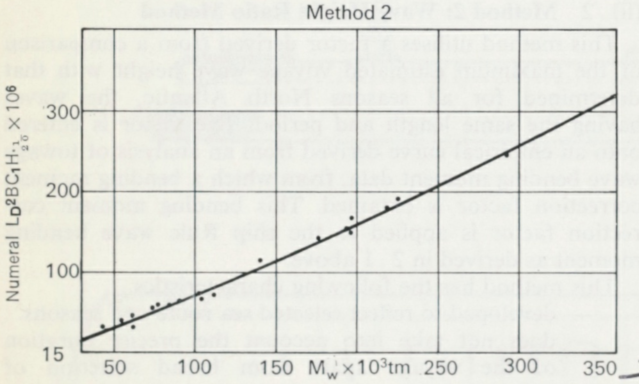

FIG. II.1

Curve of voyage M_W plotted against Numeral $L_D^2BC_1H_{\frac{1}{20}}$

It may be noted that the modulus requirement for the delivery voyage for docks in excess of 15 000 tonnes lifting capacity is often considerably in excess of the requirement for the service condition.

A sample calculation for a 36 000 tonnes dock is given below.

Longitudinal Strength:—

Service Condition

$$\text{Required } Z = \frac{12.500 \text{ L.C.}}{f}(L_D - 0.917L_S)$$

$$\text{L.C.} = 36\,000 \text{ tonnes}$$

$$L_D = 235 \text{ m}$$

$$L_S = 0.8\ L_D$$

$$f = 2200 \text{ Kg/cm}^2$$

$$Z = \frac{12.500 \times 3600}{2200}(235 - 0.917 \times 0.8 \times 235)$$

$$= 12805364 \text{ cm}^3$$

$$= 128053.6 \text{ cm}^2 \text{ m}$$

2 **TRANSVERSE STRENGTH**

The purpose of this calculation is to evaluate the maximum transverse bending moment occurring in the dock when lifting the shortest ship of weight equal to the maximum lifting capacity. The method of loading the section is given in Fig. II . 2 below. It will be noted that the effect of side loading is neglected.

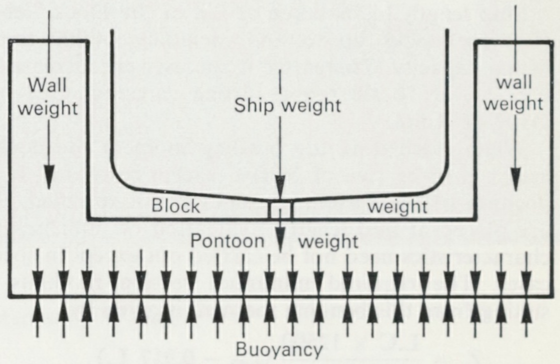

FIG. II.2

Dock Transverse Load System

The weight applied by each item (i.e. ship block, walls, pontoon, buoyancy) is defined in terms of load/unit length, the value of which are derived from the expressions below:—

$$\text{Ship Load/Unit Length} = \frac{1.167 \times \text{L.C.}}{L_S}$$

(L_S is taken as appropriate from D307)

$$\text{Keel Blocks Load/Unit Length} = \frac{1}{L_D}\left(\frac{\text{L.C.}}{600} + 43\right) \quad \cancel{\frac{1}{L_D}\,\frac{\text{L.C.} + 43}{600}}$$

If not supplied by the designers or builders, the weights of the pontoon and wing walls can be estimated from the internal volume of each item factored from the dock lightweight (LWT).

$$\text{Wing Wall Weight} = \frac{\text{Wing Wall Volume} \times \text{LWT}}{\text{Total volume}}$$

$$\text{Pontoon Weight} = \frac{\text{Pontoon volume} \times \text{LWT}}{\text{Total volume}}$$

In the case of a dock with sloping ends to the walls, the mean length must be calculated and used to derive the load/unit length. The pontoon length is usually L_D.

The method of calculation is laid out in the example below which is for a 36 000T lifting capacity dock.

L_D = 235 m

Weight of the ship = 36 000 tonnes

$L_S = 0.8 \times L_D$

$= 0.8 \times 235$

= 188 m

Ship weight/metre $= \dfrac{1.167 \times 36000}{188}$

= 223.47 tonnes/metre

Weight of keel blocks $= \dfrac{36000}{600} + 43$

= 103 tonnes

Keel blocks Wt/metre $= \dfrac{103}{235}$

= 0.438 tonnes/metre

Weight of Dock = 12800 − Keel blocks

= 12697 tonnes

Total volume of dock = 85930 m³

Volume of pontoon = 64016.5 m³

Volume of wing walls = 85930 − 64016.5

= 21913.5 m³

Weight of pontoon $= \dfrac{64016.5}{85930} \times 12697$

= 9459 tonnes

Length of pontoon = 235 metre

Pontoon Weight/metre = 40.24 tonnes/metre

Weight of wing walls $= \dfrac{21913.5}{85930} \times 12697$

= 3238 tonnes

Mean Length of Wing Walls

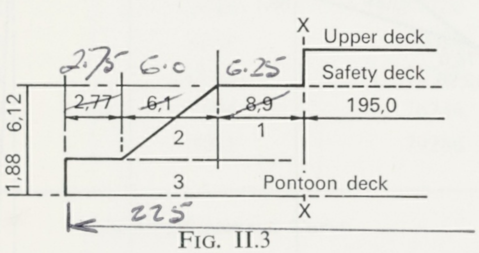

FIG. II.3

Elevation of End of wing wall

(1) Area = ~~8.9~~ 6·25 × 6.12 = ~~54.46~~ 38·25 m²

(2) Area $= \dfrac{\cancel{6.1} \; 6{\cdot}0 \times 6.12}{2}$ = ~~18.67~~ m² 18·36

(3) Area = (~~2.7~~ + ~~6.1~~ + ~~9~~) × 1.88 = ~~33.41~~ m² 28·2
2·75 6·0 6·25

N°	Area (A) m²	Lever X	A.X m³
1	38·25 ~~54.46~~	3·125 ~~4.45~~	~~242.38~~ 119·531
2	18·36 ~~18.67~~	8·25 ~~10.933~~	~~204.13~~ 151·470
3	28·20 ~~33.41~~	7·5 ~~8.885~~	~~296.83~~ 211·500
	84·81	482·501	~~743.34~~ 482·501

Mean ~~LCG~~ $= \dfrac{743.34}{106.54}$ 84·81

MEAN LENGTH FROM DATUM XX 5·6892 = ~~6.977~~ m from base xx

Mean length = 19~~6~~ + 2 × ~~6.977~~ = ~~208.95~~ m 206·378
5·6892

OF WING WALLS

Weight/metre of wing walls $= \dfrac{3238}{\cancel{208.95}}$ 206·378

15·689 = ~~15.49~~ tonnes/metre

Buoyancy = 36000 + 12800

= 48800 tonnes

Bouyancy/metre $= \dfrac{48800}{235}$

= 207.65 tonnes/metre

Note

The values of pontoon and wing wall weights, derived above, are approximations. The actual weights should always be used if these are available.

Summary

Item	Weight	Weight/metre
Ship	36 000	223.47
Keelblocks	103	0.44
Wingwalls	3238	~~15.49~~ 15·689
Pontoon	9459	40.25
	48 800	~~279.65~~ 279·84
Buoyancy	48 800	207.65

Excess weight/metre——— ~~72.00~~ tonnes
72·19

It will be seen that there is an apparent discrepancy between the total weight/metre and the buoyancy per metre.

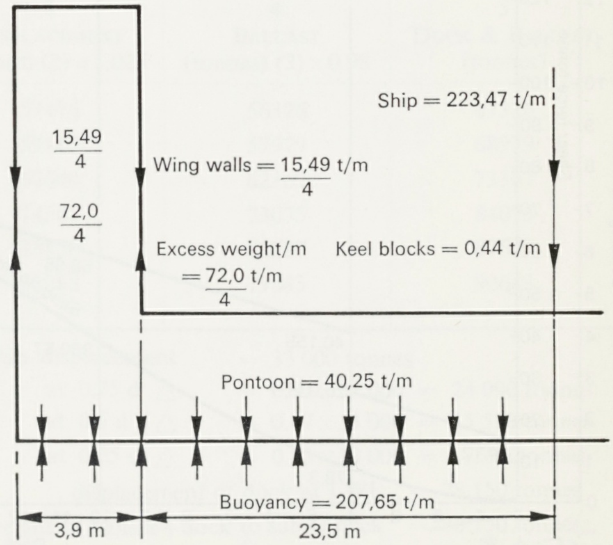

FIG. II.4

Total Load distribution: Half Dock

This arises from the assumption of L_S as 0.8 L_D and the value for ship loading, derived from the centre ordinate of the assumed ship weight distribution, being assumed to act over the whole length of the ship. The excess load is considered to be reacted by excess buoyancy at the ends of the dock and to act through the wing walls. The idealised load distribution is then, as shown in Figs. II . 4 and II . 5.

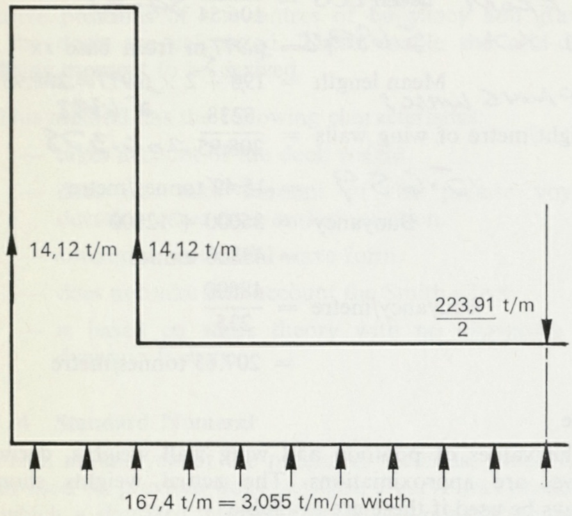

Fig. II.5

Net Load distribution: Half Dock

Shear Force Curve

Position		Shear force Tonnes
0		= 14.120
1a	$0 + 3.9 \times 3.055$	= 26.035
1b	1a + 14.12	= 40.155
2	$1b + 6.1 \times 3.055$	= 58.790
3	$2 + 5.0 \times 3.055$	= 74.065
4	$3 + 5.0 \times 3.055$	= 89.340
5	$4 + 4.0 \times 3.055$	= 101.560
6	$5 + 2.775 \times 3.055$	= 110.037
7	$6 + \dfrac{0.625 \times 3.055}{2} - \dfrac{223.91}{2}$	= 0

Bending Moment Curve

Position	Bending Moment	Aggregate Bending Moment
1	$\left(\dfrac{14.12 + 26.035}{2}\right) \times 3.9 = 78.302$	78.302
2	$1 + \left(\dfrac{40.155 + 58.95}{2}\right) \times 6.1 = 302.25$	380.572
3	$2 + \left(\dfrac{58.95 + 74.0}{2}\right) \times 50 = 332.375$	712.947
4	$3 + \left(\dfrac{74.0 + 89.1}{2}\right) \times 5 = 407.75$	1120.697
5	$4 + \left(\dfrac{89.1 + 101.2}{2}\right) \times 4 = 380.6$	1501.297
6	$5 + \left(\dfrac{101.2 + 109.9}{2}\right) \times 2.775 = 292.9$	1794.197
7	$6 + \left(\dfrac{109.9 \times 625}{2}\right) = 34.343$	1828.54

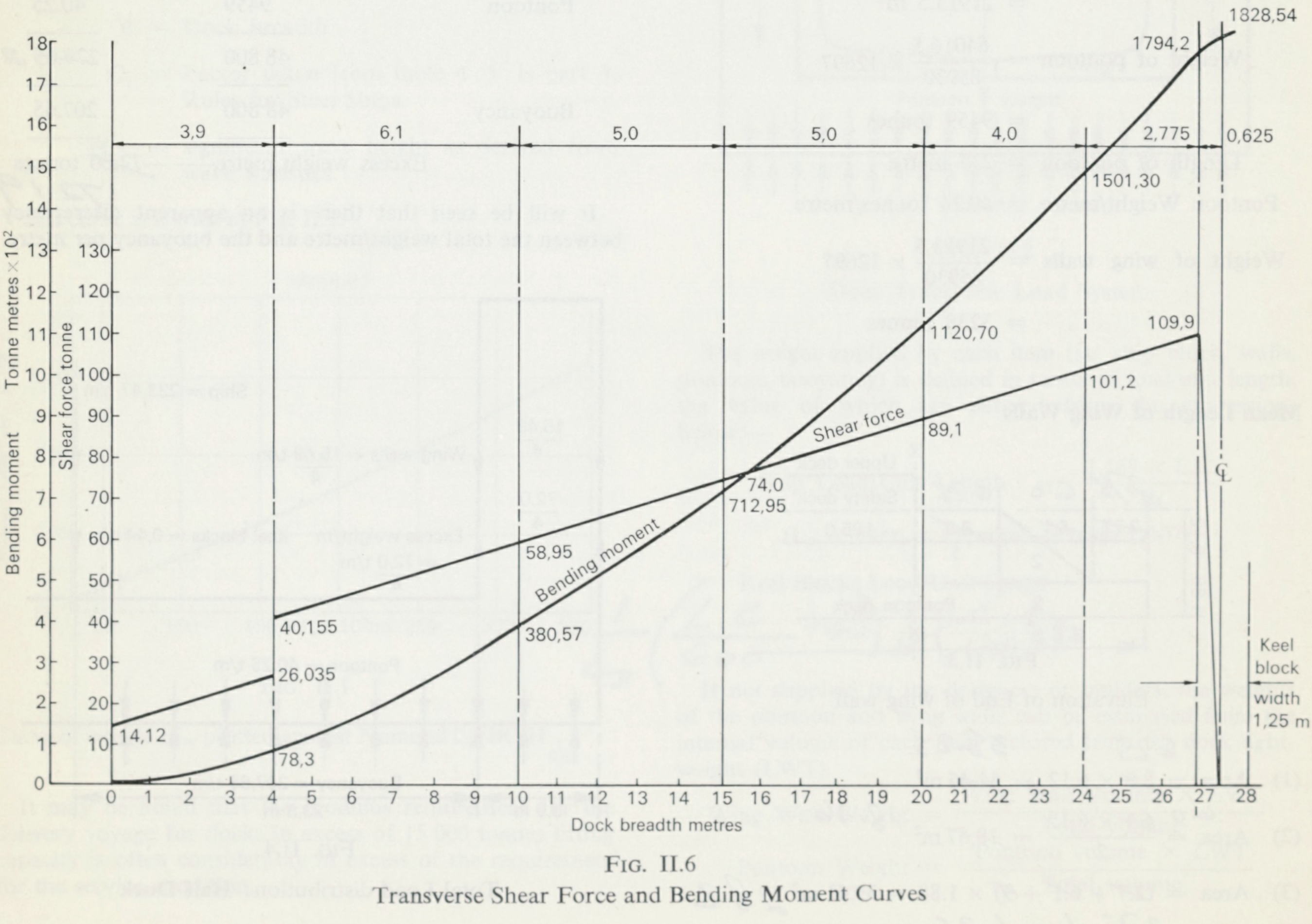

Fig. II.6

Transverse Shear Force and Bending Moment Curves

The modulii for the sections through a typical transverse girder are now calculated for positions across the width of the dock from the centre line to the wing walls. The bending stress can be calculated at each point and a stress curve plotted. Particular attention should be paid to irregularities and local reductions in the modulus, such as at manholes and openings in the web. The shear stress can also be calculated at each point, for which purpose only the web of the transverse girder is considered to be effective. The bending and shear stresses are then in the following expression to determine a combined stress:—

$$\sigma_{com} = \sqrt{\left(\sigma_b^2 + 3\tau_c^2\right)}$$

The allowable values are as follows:—

Bending stress	(σb)	=	1730 kg/cm^2
Shear stress	(τc)	=	975 kg/cm^2
Combined stress	(σcom)	=	1950 kg/cm^2

It is normal practice for the tensile and compressive stresses in the transverse pontoon frames from the transverse strength calculation to be added algebraically to the bending stresses in the frames from hydrostatic pressure. For this purpose the hydrostatic head used in the calculation should be lifted from the curves at the point level with the top of the keel blocks. This gives the worst possible loading. The allowable stress for this combined bending from transverse and hydrostatic loading is taken as 1510 kg/cm^2, and not the normal allowable of 1340 kg/cm^2 required by the Rules.

3. HYDROSTATICS AND PUMPING DIAGRAM

The purpose of this diagram is to enable the designers to obtain the normal weights and displacements of the dock at any draught, and, resulting from this, the differences in waterlevel inside and outside the dock when lifting the ship.

Also obtained is the length of any air pipes necessary to restrict the ballast intake so ensuring that there is sufficient reserve of buoyancy to keep the dock afloat with the inlet valves open.

The method used is as follows:

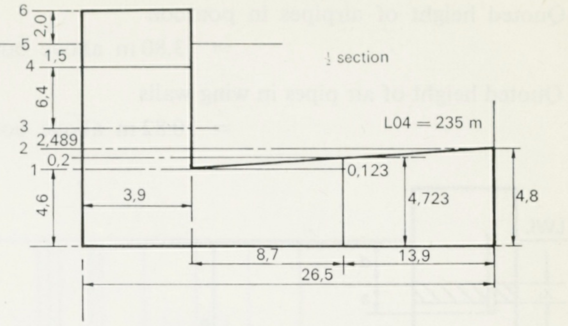

Fig. II.7

Dock half section

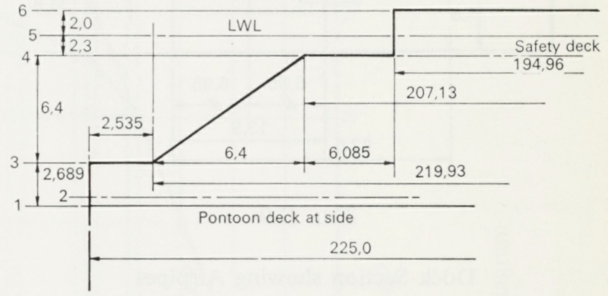

Fig. II.8

Arrangement of wing wall Ends

Volumes (½ Dock)

0 to 1 V = 230 × 26.5 × 4.6 = 28 037 m^3

1 to 2 V = $235\times 13.9\times\left(\frac{0.123+0.2}{2}\right) + \left(\frac{0.225\times 8.7\times 0.123}{2}\right) + 225\times 3.9\times 0.2$ = 823 m^3

2 to 3 V = 225 × 3.9 × 2.489 = 2184 m^3

3 to 4 V = $\left(\frac{219.93+207.13}{2}\right)\times 3.9\times 6.4$ = 5330 m^3

4 to 5 V = 194.96 × 3.9 × 2.3 = 1749 m^3

5 to 6 V = 194.96 × 3.9 × 2.0 = 1521 m^3

Position	1 Volume (m^3)	2 Aggregate Volume (m^3)	3 Displacement (tonnes) (2)×1.025	4 Ballast (tonnes) (3)×0.98	5 Dock & Ballast (tonnes)
1	56074	56074	57476	56326	67326
2	1646	57720	59163	57979	68979
3	4368	62088	63640	62367	73367
4	10660	72748	74567	73075	84075
5	3496	76244	78150	76587	87587
6	3042	79286	81268	79643	90643

Ship Displacement Curve

The curve used is a standard distribution derived from a statistical analysis of ship types.

draught over keelblocks = 9.7 m

block clearance = 0.3 m

draught of ship = 9.4 m

$\frac{d}{4}$ = 2.35 m

ship displacement = 33 000 tonnes

at 0.75 d $\triangle$ = 0.73×33 000 = 24 090 tonnes

at 0.5 d $\triangle$ = 0.47×33 000 = 15 510 tonnes

at 0.25 d $\triangle$ = 0.23×33 000 = 7590 tonnes

displacement of dock at LWL = 78 150 tonnes

weight of ballast+dock to safety deck = ~~78 150~~ tonnes 84075

reduction in ballast required for equilibrium = 84 075 − 78 150 = 5925 tonnes

Air pipes

Quoted height of airpipes in pontoon

$= 3.80$ m above bottom

Quoted height of air pipes in wing walls

$= 10.82$ m above bottom

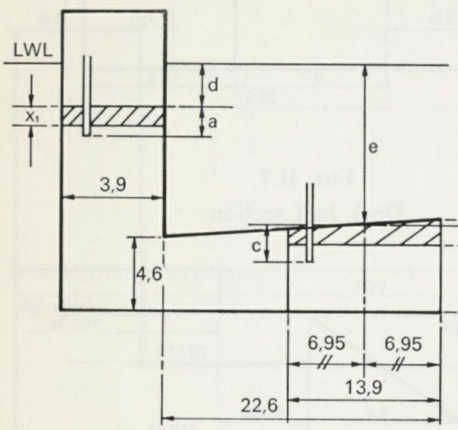

FIG. II.9

Dock Section showing Airpipes

$$a = 13.7 - 10.82 = 2.88\text{ m}$$

$$d = 2.3\text{ m}$$

$$e = 9.7 + 1.5 + 0.2\left(\frac{6.95}{22.6}\right) = 11.26\text{ m}$$

$$c = 4.8 - \frac{0.2 \times 6.95}{22.6} - 3.8 = 0.938$$

using standard method: for pontoon

$$c = \left(\frac{10.084 + e + x_2}{10.084}\right) x_2$$

$$0.938 = \left(\frac{10.084 + 11.62 + x_2}{10.084}\right) x_2$$

$$10.084 \times 0.938 = 10.084x_2 + 11.26x_2 + x_2^2$$

$$0 = x_2^2 + 21.344x - 9.463$$

$$x_2 = \frac{21.344 \pm \sqrt{21.344^2 + 4 \times 9.463}}{2}$$

$$= \frac{-21.344 \pm 22.213}{2}$$

$$= -21.779 \text{ or } + 0.435$$

volume of air space under pontoon dock for whole dock

$$= 0.435 \times 13.9 \times 2 \times 235$$
$$= 2841.86\text{ m}^3$$
$$= 2912.9\text{ t}$$

buoyancy to be found from wing walls

$$= 5925 - 2912.9$$
$$= 3012.1\text{ t}$$
$$B = 2938.6\text{ m}^3$$

width of walls $= 3.9$ m
length of safety deck $= 207.13$ m

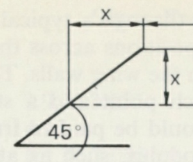

FIG. 10

mean length of air cushion

$$L_e = 207.13 + \left(\frac{x}{2} \times 2\right) \text{ metres}$$

volume of air cushion

$$\frac{2938.6}{2} = L_e \times x \times 3.9$$
$$= (207.13 + x) \times 3.9 \times x$$
$$= (207.13 \times 3.9)x + 3.9x^2$$
$$\frac{2938.6}{2} = 807.8x + 3.9x^2$$
$$\text{i.e. } 0 = x^2 + 207.13x - 376.74$$
$$x = \frac{-207.13 \pm \sqrt{207.13^2 + 376.74 \times 4}}{2}$$
$$= \frac{-207.13 \pm 210.74}{2}$$
$$= -208.93 \text{ or } + 1.8 \text{ metres}$$

Check

volume of air cushion $= (207.13 + 1.803) \times 3.9 \times 1.803$
$= 1469.3$

$$\frac{2938.6}{2} = 1469.3$$

length of wing wall air pipe

$$a = \frac{(10.084 + d)\ x_1 + x_1^2}{10.084}$$
$$= \frac{(10.084 + 2.3)\ x\ 1.803 + 1.803^2}{10.084}$$
$$= 2.537 \text{ m below S.D.}$$
$$= 13.7 - 2.537$$
$$= 11.163 \text{ m above base}$$

Designers calculated

value $= 10.82$ m above base

4. LOCAL STRENGTH

The local strength is normally verified by using the relevant paragraphs of the Rules. There are however certain items for which there are no Rules at present. Principal among these is the bottom plating of transversely framed docks. When a dock is poised on a wave, with the crest at amidships, the bottom of the dock is subjected to a compressive loading. The bottom of the dock is normally transversely framed, with fairly wide short panels of plating bounded by stiff longitudinal girders. Some designers, when estimating the scantling requirements for the dock bottom, assume that the plating will buckle between the longitudinal girders, and that the maximum stress in the plating will not exceed the yield stress of the material since this will result in permanent set of the bottom plating. In L.R. the bottom scantlings of such docks are normally examined using a method derived from standard plate buckling theory which includes an allowance for the stiffness of the longitudinal girders and the initial deformation of the panel due to welding and hydrostatic pressure. The stress limit for this method is 0.9 Yield of the bottom plate material.

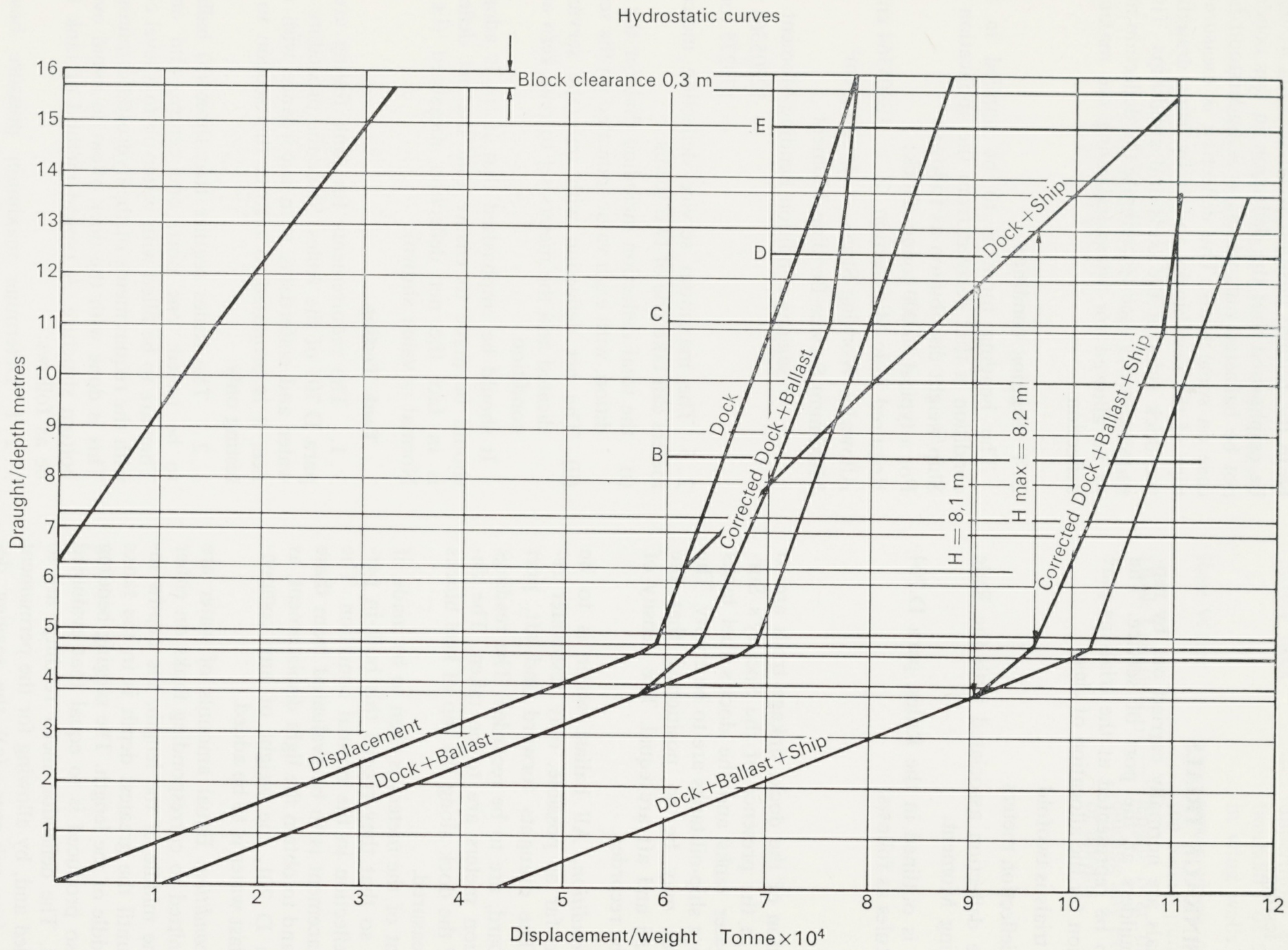

FIG. II.11

Hydrostatic curves and Pumping Diagram

APPENDIX III

AMPLIFICATION OF L.R. RULES

1. A considerable degree of amplification of the Society's Floating Dock Rules has been given in Appendix II.

There are, however, two areas in which experience has shown that guidance may be required: viz the dock acceptance sinkage trials and tank testing.

2. SINKAGE TRIALS

2.1 The sinkage trials are normally carried out by representatives of the builders at the port of service. The Society is required to be represented at the trials as part of the general inspection for the allocation of class.

The purpose of the trials is twofold

(i) to calibrate the deflection meters

(ii) to determine the deflection associated with the Rule Maximum Bending Moment.

2.2 The procedure is outlined in the Rules, para D.704 of the floating dock Rules as follows.

"Sinkage trials

704 On the completion of the dock, sinkage trials are to be carried out in the presence of the Society's Surveyor. Fresh water tanks and the dock's fuel tanks are to be full, but ship-oil tanks are to be empty. The travelling cranes may be so positioned that the draughts forward and aft are equal. The density of the water is to be recorded.

(a) *Normal condition.* All ballast water is to be emptied so far as possible, only rest-water remaining. The draughts forward and aft, port and starboard, are to be recorded. The readings on deflection meters are to be taken. The deflection of the dock along the top of keel blocks is to be measured.
Adjustment of the meters is then to be made, if necessary, so that they record this built-in permanent deflection in the normal condition. The light displacement is to be evaluated from these readings, and to obtain the light displacement, as defined in D 201, the weight of any compensating ballast water is to be added.

(b) *Sagging condition.* Equal amounts of water are to be admitted to corresponding tanks on either side of the middle of the length, the depths increasing until the greatest depth is in the tanks at the middle of the length. The sagging bending moment so produced is to equal that evaluated in D 303. The deflection meter readings are to be recorded and, by allowing for the permament deflection (*see* sub-para. (a)) the sagging deflection obtained.

Alternative arrangements to those described in (b) will be specially considered.

705 When estimating the quantities of ballast water for 704 (b), the permissible difference in height of ballast water in adjacent compartments is not to exceed the pressure head for the compartments as laid down in D 508."

2.3 **Normal condition**

The purpose of the normal condition test is to ascertain the dock deflection in the light condition with the ballast tanks emptied as far as is practicable. The cranes should be in the normal position when docking a ship. It should be emphasised that the deflection in this condition should not be ballasted out, which, it is understood has been the case on some trials. The deflection is measured along the tops of the keel blocks and/or by using draught gauges on the dock sides at the ends and amidships. The deflection so measured is used to calibrate the deflection meters and is to be allowed for when indicating the maximum service deflection.

2.4 **Sagging condition**

The bending moment to be applied in the sagging condition is that derived from the application of the Rule Ship/weight distribution as follows.

For a typical 36 000 tonnes Dock:

Required Rule Mid Section $Z = 12805364 \text{ cm}^3$

Allowable Working Stress $= 1400 \text{ kg/cm}^2$

Maximum Service Bending Moment

$$= \text{sagging condition Bending Moment}$$
$$= 12805364 \times 1400 \times 10^{-5}$$
$$= 179275 \text{ tonne metre.}$$

2.5 The maximum service deflection indicated by the meters can take one of two forms.

(i) the total deflection including that for the normal condition, with each value indicated on the scales.

(ii) The net deflection with only the service values indicated and the meters set to read zero at the normal condition.

It should be emphasised that if (ii) is adopted a check should be made to ensure that the net deflection shown is in fact the net deflection measured (i.e. Sagging − Normal = value shown).

3. **Tank Testing**

3.1. The requirements for tank testing are outlined in para D 703 of the Rules. Since the procedure for oil, fresh water and cofferdams is in accordance with normal practice, it is proposed to restrict this section to ballast tank testing only.

3.2. The Rules require that three (3) ballast tanks are to be tested: one port, one centre, and one starboard. They are to be filled with water up to a level commensurate with the requirements of the hydrostatics/pumping diagram. This is done with the dock afloat to avoid overloading the bottom structure. A typical method of tank testing would be as follows:

3.2.1 Determine maximum pressure head from the pumping diagram (H_{max} on curve)

3.2.2 Fill all ballast tanks up to pontoon deck level

3.2.3 Pump extra ballast into tank to be tested up to level of H_{max} above pontoon deck

3.2.4 Pump out ballast in tested tank down to pontoon deck level

3.2.5 Repeat for other tanks

3.2.6 Pump out dock

3.2.7 Inspect for any structural damage

3 . 3 Whilst it is appreciated that there are other methods of achieving the desired results, the aforementioned method has the following advantages:—

3 . 3 . 1 There is no likelihood of overloading the bottom structure.

3 . 3 . 2 The tank boundaries are subjected to the necessary pressure head as uniform pressure over the depth of each bulkhead, as would be the case with the dock in service.

3 . 4 In addition to the selective structural test, all ballast tanks must be subjected to a leak test by air pressure. The methods of carrying out such a leak test are well known and do not need any further amplification here.

GLOSSARY OF TERMS

Pontoon	—	the main hull of the dock, providing the principal lift.
Wing Walls	—	narrow vertical tank extensions arranged along each side of the pontoon providing the stability when the dock is submerged, and, in the case of a pontoon type dock, the longitudinal strength in way of the pontoon gaps.
Upper deck	—	uppermost continuous deck of wing walls.
Safety deck	—	uppermost watertight deck; upper boundary of the main ballast tanks in wing walls.
Rest Water	—	water which cannot be removed by the ballast pumps.
Dock Length (L_D)	—	length over the pontoon deck, excluding any extensions of wing walls or aprons.

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DESIGN AND CONSTRUCTION ASPECTS OF CONTAINMENT SYSTEMS FOR THE CARRIAGE OF LIQUEFIED GASES IN SHIPS

A. G. Gavin

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FOR PRIVATE CIRCULATION AMONGST THE STAFF ONLY

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DESIGN AND CONSTRUCTION ASPECTS OF CONTAINMENT SYSTEMS FOR THE CARRIAGE OF LIQUEFIED GASES IN SHIPS

By A. G. GAVIN

TABLE OF CONTENTS

1 INTRODUCTION

Liquefied gas is a natural resource and may be viewed as a gift from the past to fulfil our present needs in providing a relatively pollution free source of energy. It is said that 'Beauty lies in the eye of the beholder' and, as such, the merits and disadvantages of liquefied gas can be seen in this light. On the one hand, it provides an accessible energy source and, on the other, it introduces a total risk instigated by the many variables involved in the transportation from source to consumer.

Transporting liquefied gas by sea requires special engineering techniques and contingency measures to minimize the risks created by the hazardous nature of the cargoes carried. It is the Society's purpose in the classification of such ships to ensure that these ships are built and maintained to a standard which enables a high confidence level to be attained, and hence, minimize the dangers to the immediate operational area.

In considering the problems associated with the containment of liquefied gases on board ship, it should be recognized that, in general terms, the ship as a whole is the containment system with the outer elements of the hull providing the very necessary cocoon for safe transportation. For design purposes, however, it is necessary to differentiate between those elements directly containing the cargo and those relating more to the safe carriage of the cargo. In this respect, the containment system can be defined as that which immediately contains the cargo and provides cryogenic (thermal) protection to the hull of the ship. In terms of safety, the emphasis is not only to contain the hazardous gas cargoes within the ship but also to prevent leakage of salt water from the ballast tanks or the seaway, as both these aspects can endanger cargo containment.

When considering the hulls of these ships, the Society applies the extensive experience gained with the classification of steel ships over many decades much of which is reflected in the present Rules and Regulations and other individual procedures and practices which relate to both major and also more detailed aspects of structural design.

The nature of the cargoes carried has led to the development of a number of ingenious concepts for containment, many of which are in service today, and it is on this aspect that this paper is concentrated.

It is intended that the paper will cover the various topics that affect the Society's role in the review and approval of these systems from the strength aspect. These include particulars of the composition of the cargo and its hazards, the history of the development of containment systems, the participation of the many bodies involved in the preparation of regulations, the categories of containment types, and the necessary fabric for the verification of the system to support the Society's approval. The paper is concluded with a concise description of the status of the containment systems submitted to the Society divided into their respective categories.

It is hoped that the Society's Surveyors will find this paper a useful adjunct to the invaluable papers written by Davies and Atkinson/Sumner and Navaz (*see* Bibl. Nos. 22, 23 and 24).

2 THE NATURE OF THE PRODUCT

The gases commonly associated with the carriage of gas by sea are Liquefied Natural Gas (LNG) and Liquefied Petroleum Gas (LPG). Liquefied Natural Gas is the liquid form of a low molecular weight saturated hydrocarbon mixture. It originates underground from the metamorphosis of miscroscopic organisms, as is the case with crude oil, and is found in conjunction with crude oil or in gas fields alone. Its composition is primarily methane with the percentage of the constituents dependent on geographical source and also, after extraction, on the amount of processing during liquefaction to remove the heavier hydrocarbons, principally propane and butane, which have a commercial market separate from natural gas. The main areas of extraction are shown in Table 1 together with the percentage composition of constituent gases.

Liquefied Petroleum Gases may be obtained from gas fields or extracted during the refining process of crude oil and consist

primarily of the heavier hydrocarbons propane, propylene, butane, butylene, butadiene, ethylene and their mixtures. Other gases such as anhydrous ammonia and vinyl chloride are generally included in this category.

It should be understood that all natural gases and gases described as LPG occur as gases at Standard Temperature and Pressure, 0°C and 1.013×10^5 N/m^2, and that they require to be pressurized and/or cooled to maintain them in a liquid state.

A diagram showing a typical pressure-volume-temperature relationship is included to emphasize a particular characteristic in the liquefaction of gas, *see* Figure 1. This diagram shows the states in which a gas may exist dependent on the temperature and pressure applied. At high temperatures (the isothermic curves on the right of the diagram), the gas exists in a gaseous state and, conversely, with the curves on the left of the diagram, the gas exists in a liquid state. The horizontal part of any isotherm, shown within the dotted line, indicates the area in which a gas exists in both a liquid and gaseous state. It can be seen that above a certain temperature, known as the critical temperature, any increase in pressure will not bring about the liquefaction of the gas. This critical temperature of a gas, therefore, becomes a major factor in the determination of the mode of carriage for the proposed cargo. The pressure required to cause liquefaction at the critical temperature is called the critical pressure.

A gas that has a critical temperature above ambient, such as propane, butane and ammonia, may be transported in pressure vessels at ambient temperature. In the case of propane with an ambient temperature of +5°C, a pressure of approximately 5.5 kg/cm^2 would be required.

A gas with a critical temperature lower than a design ambient such as methane and ethane, is normally cooled to its boiling point which, in the case of methane, is −161.5°C at atmospheric pressure. This procedure can also of course, be adopted with the gases previously mentioned, propane and butane, etc., whereas propane would be cooled to −42.3°C for carriage.

The temperature/vapour pressure relationship for a selection of gases carried by ship is shown in Fig. 2.

Another major consideration in understanding the nature of the cargo is to review the behaviour of the gas in uncontrolled circumstances.

Experimental data reveals that when LNG is spilled on water, the pool of gas formed spreads outwards continuously until evaporation is complete with the rate of evaporation increasing as the boundary of the spill extends. The violent nature of the boiling gas prevents the formation of ice on the water surface.

In the event that damage to the containment vessel causes the release of LNG below water level, it has been found, from small scale experiments conducted in the United States, that the liquefied gas becomes completely evaporated by the time it reaches the surface.

After the leakage of natural gas, a vapour cloud may form, provided ignition has not already taken place. The vapour cloud disperses downwind shaping into a long thin cloud remaining close to the surface due to its vapour density. In unfavourable weather conditions, this cloud may travel a considerable distance before the dilution of air renders it harmless.

The burning of the natural gas in a confined space can produce overpressures that will destroy the containment vessel. The burning of a vapour cloud which is unconfined should only prove harmful in pressure terms to that within its boundaries. The intense heat exuded will certainly cause extensive damage within a limited range of the burning vapour cloud. It is not known whether an unconfined burning vapour cloud can explode as no evidence of this possibility exists.

Another phenomenon known as 'rollover' maybe of interest with regard to floating storage vessels as it has occurred on land-based storage vessels.

The boiling point of natural gas increases as the density of the liquefied gas increases. In a condition where a heavy density LNG is added to a light density LNG, stratification may occur with the heavier liquid gravitating to the bottom of the tank. As heat is imparted to the cargo from the surrounding boundaries, the lighter liquid will expand and evaporate but the lower heavier LNG will only warm, being constrained by the upper layer. As the density of the lower gas approaches the density of the upper liquid, the lower liquid rises through the upper layer, expands, mixes and boils rapidly. This phenomenon is called 'rollover' and may cause the collapse of the containment structure if the emergency valves cannot handle the sudden increase in pressure. This situation is unlikely to occur in ships however since the cargo is normally loaded from one location and the motion of the ship in a

Constituent	Location					
	Algeria	Libya	Brunei	North Sea	Iran	Alaska
Methane	86.3	66.8	88.0	85.9	96.3	99.5
Ethane	7.8	19.4	5.1	8.1	1.2	0.1
Propane	3.2	9.1	4.8	2.7	0.4	—
Butane	0.6	3.5	1.8	0.9	0.2	—
Pentane and Others	0.1	1.2	0.2	0.3	0.1	—
Nitrogen	—	—	0.1	0.5	1.3	0.4
Carbon Dioxide	—	—	—	1.0	—	—

GENERAL COMPOSITION OF VARIOUS NATURAL GASES

TABLE 1

seaway would in any case thoroughly mix any combination.

Generally, saturated hydrocarbons are chemically inactive. In the case of leakage into water, methane can undergo a clathrate formation but this is very slow and is considered insignificant. The most important reaction is, of course, combustion with its associated hazards. Methane is not considered an air or water pollutant, although the marine biologist may argue that the effects on life forms, e.g. plankton, exposed to the gas may lead to a local state of pollution.

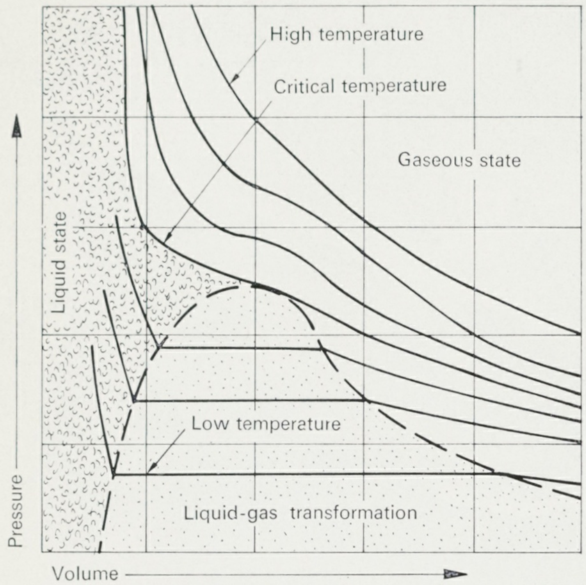

FIG. 1

A typical pressure—volume—temperature relationship for a gas.

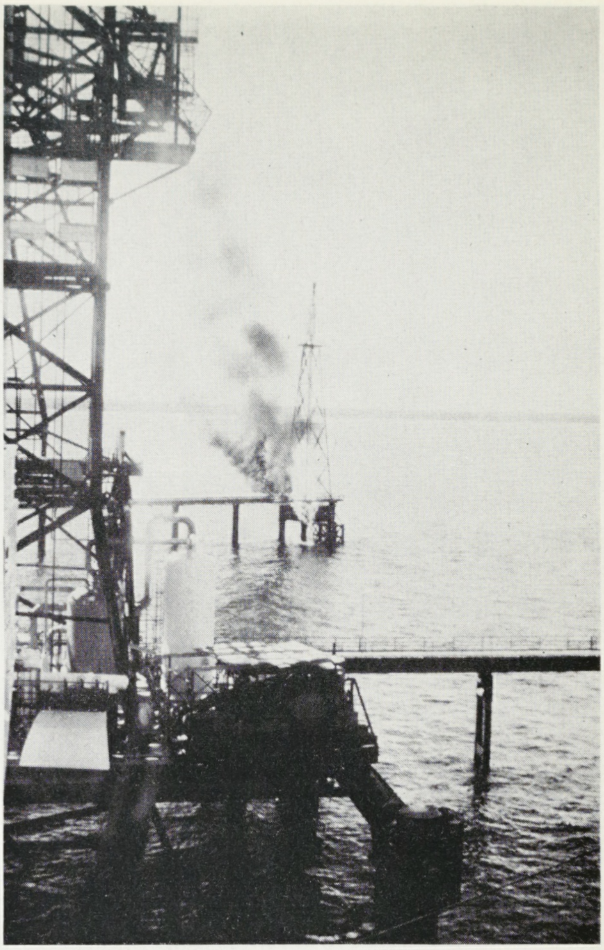

PLATE I. LNG terminal spillage fire.

Gas	Specific gravity	Boiling point	Critical temp.
Methane	0,474	−161°C	−83
Ethylene	0,57	−104°C	+9
Ethane	0,574	−89°C	+32
Propylene	0,614	−48°C	+92
Propane	0,583	−42°C	+97
Ammonia	0,683	−33°C	+132
Vinyl chloride	0,965	−13°C	+157
Butadiene	0,647	−4°C	+152
Butane	0,602	−1°C	+152

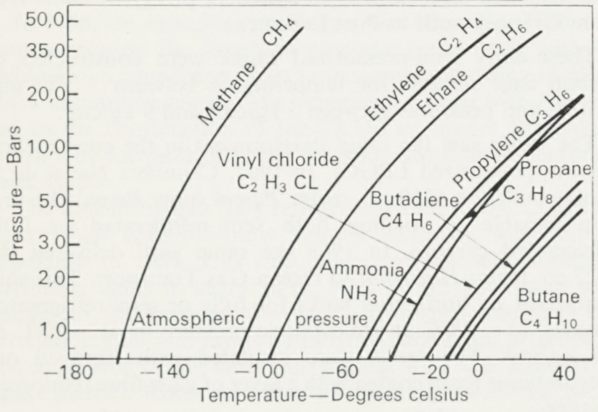

FIG. 2

The temperature/vapour pressure relationship for a selection of gases.

3 CHRONOLOGY AND DEVELOPMENT OF LPG CONTAINMENT SYSTEMS

The birth of containment systems for the carriage of liquefied petroleum gases by sea can be classed into three distinct phases according to the type of configuration under development. These subdivisions appertain to the method of transportation as follows:

(i) Fully pressurized carriers
(ii) Semi-pressurized carriers
(iii) Fully refrigerated carriers.

Fully pressurized carriers:

The first attempt to transport LPG by sea occurred in the United States in 1931 using uninsulated pressure vessels aboard the *Aquinita*. This experiment was curtailed with the grounding of the ship.

In 1934, the *Megara*, an LR classed oil tanker built at Chantiers de la Seine Maritime in 1929, was fitted with cylindrical tanks within her centre cargo tanks for the carriage of propane and butane. This ship was later used as a depot ship at Gibraltar before demolition in 1958.

At this stage the development of gas transportation revolved round the conversion of dry cargo ships to carry LPG, although by 1946 propane was being conveyed in barges on the Mississippi.

In 1947, the 6050 cu. metre *Natalie O. Warren*, a converted dry cargo ship, was delivered by the Bethlehem Steel Company. The ship was fitted with 68 vertical cylindrical pressure vessels in five holds for the carriage of propane from Houston to New York. The following year the *Rio Novo* was converted

PLATE II. The 27 400 cu. metre *Methane Princess* fitted with Conch independent tanks.

for Øivind Lorentzen of Norway for the ocean transportation of 3000 cu. metres of propane and/or butane in 29 vertical and two horizontal tanks. In 1952, two further conversions by Kieler Howaldtswerke, the *Mundogas Sao Paulo* and the *Mundogas Norte*, were delivered for the Texas to Brazil and, later, Brazil to Argentina route.

The 1940s and early 50s showed the increase in interest of coastal movement of LPG in Europe. A specially designed 1042 cu. metre gas carrier, *Ras Tholstrup*, equipped with 12 upright cylindrical tanks was built in 1953 at the Swedish Marstrand shipyard. This ship was followed in 1954 by the *Sorine Tholstrup* built by AS Svendborg of Denmark which incorporated a single 175 cu. metre horizontal tank. These ships heralded the emergence of small fleets of liquefied petroleum gas carriers (LPGCs) throughout Europe.

By 1965, Gazocean owned eight fully pressurized LPGCs comprising five newbuildings and three conversions.

Semi-pressurized carriers:

The first carrier to appear to include refrigeration plant on board was the 2100 cu. metre *Descartes* built at La Ciotat in 1959 for Gazocean.

The 1960s saw the building of semi-pressurized 'Tholstrup' vessels, among them the *Lili Tholstrup* and the *Birthe Tholstrup* from the Aarhus yard, Denmark, in 1961 and '62. These ships were built to withstand 8.5 kg/cm^2 at -10°C.

In the early 1960s, three Spanish yards contracted to build seven semi-pressurized LPGCs of 2000 cu. metres each for Butano S.A.

In 1964, Hawthorn Leslie converted the *Abbas* into a semi-pressurized LPGC to carry 755 cu. metres of iso-butylene in two insulated steel horizontal cylinders (8 kg/cm^2 at -7°C) from Grangemouth to Port Lerome.

These early semi-pressurized tanks were constructed of carbon steel suitable for temperatures between -5°C and -10°C and pressures between 5 kg/cm^2 and 9 kg/cm^2.

The 1960s saw the rapid development in the construction of semi-pressurized LPGCs. In 1967, Chantiers Naval de la Ciotat built the 6310 cu. metre *Pascal* (now *Berga*) the first ship capable of loading both semi-refrigerated or fully refrigerated cargoes. In 1968 the same yard delivered the 6327 cu. metre *Humboldt* to Ocean Gas Transport. This ship comprised six horizontal tanks for fully or semi-refrigerated cargoes, at -48°C at atmospheric pressure or at -10°C at 7.5 kg/cm^2. The tanks were insulated with 'sprayed on' polyurethane foam coated with a layer of glass fibre reinforced plastics.

Today's semi-pressurized carriers have the ability to carry either semi-refrigerated at -10°C or fully refrigerated cargoes at -48°C since tanks and piping are constructed of special quality low temperature fine grain carbon steel.

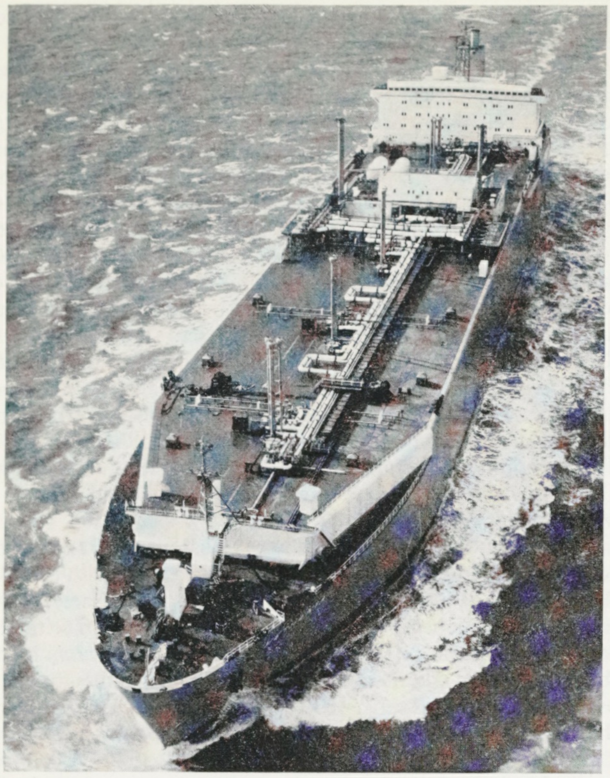

PLATE III. The 131 000 m³ *Methania* fitted with the Gaz-Transport membrane system.

Fully refrigerated carriers:

The pioneer work into fully refrigerated cargoes was conducted by Conch, Technigaz and Øivind Lorentzen in considering the transportation of LNG cargoes.

In 1961, the Société Maritime Shell had the 10 270 cu. metre *Iridinia* converted to carry butane at atmospheric pressure. The following year, the first purpose built fully refrigerated LPGC, the 28 875 cu. metre *Bridgestone Maru* was completed by Mitsubishi, Yokohama. This ship was built to Conch International Methane Limited design to carry propane and butane at atmospheric pressure at −41°C. This ship was followed, in 1964, by the 36 000 cu. metre *Bridgestone Maru II*, built at the same yard with an improved system of tank supports by Bridgestone, and, in 1966, by the 46 720 cu. metre *Bridgestone Maru III* built at IHI entirely to Bridgestone specification.

In 1965, the experimental *Bridgestone Maru No. 1101* went into service on the Japanese domestic trade fitted with the Bridgestone membrane cargo tank system consisting of 2 mm thick aluminium panels. The experience gained with this ship led to the construction of the 72 350 cu. metre *Bridgestone Maru V* by Kawasaki utilizing the Bridgestone semi-membrane tank system.

The first European fully refrigerated LPGC, the 25 012 cu. metre *Paul Endecott* (now *Norfolk Multina*), was built at Kockums in 1964. This ship comprised five self-supporting prismatic tanks to carry LPG, NH_3 or ethylene oxide at a minimum temperature of −51°C. This ship employed two overlapping 50 mm layers of polyurethane foam attached to the inner side of the inner hull plating with the interbarrier space inerted. Kockums followed this design with the 26 500 cu. metre *Phillips Arkansas* (now *Amy Multina*) in 1969.

In 1964, the 12 975 cu. metre *William R. Grace* was built at Verolme, Netherlands. This ship was the first of three similar 12 975 cu. metre LPGCs completed for Oswego Chemical Carriers Corp., each comprising four rectangular tanks, to carry LPG from Trinidad to terminals on the US Gulf and East Coasts to Europe.

In August 1966, the first of two fully refrigerated ethylene carriers was built at Burntisland, the 826 cu. metre *Teviot* to carry ethylene from ICI's plant on Teesside to Rozenburg. The ship had one self-supporting tank of aluminium-magnesium alloy covered with a 150 mm layer of expanded polyurethane insulation. The second ship, *Traquair*, was delivered two months later. At this time, A.G. Weser built the 830 cu. metre *Lincoln Ellsworth* which incorporated a single cylindrical 5 per cent. nickel steel tank encased in a double hull.

Shell International Marine began the development of a polyurethane foam internal insulation system in 1965 primarily for the carriage of LPG. This system was fitted to the experimental tanks installed on the tanker *Aulica* in 1969. This system was later fitted to the 77 500 cu. metre *Pioneer Louise* built in 1976 by Mitsubishi, and the *Gas Gemini* and *Gas Diana* in 1977 from the same yard.

In 1972, P & O Bulk Shipping Division took delivery of the 29 800 cu. metre *Gazana* from Cammell Lairds.

By 1970, the need for long distance carriers/tankers, in the 50 000 cu. metre and upwards range, emerged for the Persian Gulf to Japan, and Canada/US to Japan routes. In 1973, the 100 200 cu. metre *Esso Fuji* was built at Hitachi Zosen comprising four prismatic tanks insulated with polyurethane foam, and in 1974, the 99 300 cu. metre *Palace Tokyo* was completed. Both these ships were built to carry propane and/or butane from the Persian Gulf to Japan.

By the beginning of 1978, the World Fleet of LPG and Ethylene Carriers stood at 517 ships of which 10 were over 100 000 cu. metres in capacity.

4 CHRONOLOGY AND DEVELOPMENT OF LNG CONTAINMENT SYSTEMS

The carriage of LNG required total commitment by the pioneering Companies and it is as well to acknowledge those companies who have had the courage to make the carriage of LNG a feasible operation.

The first steps towards the transportation of LNG, by sea were mooted in 1952 by Constock Liquid Methane Corporation. This company was formed by the Union Stockyard and Transit Company and the Continental Oil Company to research into the feasibility of carrying LNG by river up the Mississippi from the US Gulf Coast to Chicago. This project was eventually abandoned, due to economic reasons. However, a change of interest from river to ocean transportation instigated the development of a prototype vessel, the 6000 cu. metre barge *Methane*, but this vessel did not see service.

The evolvement of Constock in the field of large scale LNG carriage was further developed in 1957 when they were joined in a project by the North Thames Gas Board. This project involved the conversion, in 1958, of a dry cargo ship, to the 5000 cu. metre *Methane Pioneer*, which in 1959 carried its first cargo of LNG from Lake Charles, Louisiana, to Canvey Island. This project was terminated in 1961 after seven voyages. However, the *Methane Pioneer* saw further service on the east coast of the USA.

In 1960, Shell joined the parent companies of Constock, in ownership, to form a new partnership, Conch International Methane Limited. This company, together with the British Gas Council, contracted Vickers Armstrong and Harland & Wolff to build two 27 400 cu. metre LNG ships *Methane Princess* and *Methane Progress* for delivery in 1964 for the Arzew, Algeria, to Canvey Island route. These ships were fitted with the self-supporting Conch containment system. A further development was seen in the evolvement of a membrane system tested on a 270 cu. metre tank installed on the collier *Findon* in 1964. This project proved unsuccessful.

In 1960, Methane Transport was set up principally by Gaz de France and Worms & Cie. to evaluate the different tank configurations for LNG carriage. A liberty ship *Beauvais* was fitted with one prismatic aluminium-magnesium alloy tank at Chantiers de l'Atlantique, one multi-lobed 9 per cent nickel steel tank at Ateliers et Chantiers de Dunkerque et Bordeaux and one cylindrical aluminium-magnesium alloy tank at Ateliers et Chantiers de la Seine Maritime and Forces et Chantiers de la Mediterranee, for this purpose. All the tanks were insulated with expanded PVC. The results of these tank tests, conducted in 1962 for a period of five months, led Gaz de France to use cylindrical tanks, on board the 25 500 cu. metre *Jules Verne*. This ship was built in 1965 at Ateliers et Chantiers de la Seine Maritime for the carriage of LNG from Arzew to Le Havre.

Worms & Cie. and Gaz de France formed Gaz Transport in 1964 and, utilizing the experience gained in the following years with the *Jules Verne*, conceived the Gaz Transport Membrane system based on an Invar Membrane (36 per cent nickel steel) and perlite insulation contained in plywood boxes. This system was first used, in part, on the 3300 cu. metre LPG ship *Hypolite Worms* in 1968 and then, in full, in 1969 on two 71 500 cu. metre LNG tankers *Polar Alaska* and *Arctic Tokyo* built at Kockums to operate between Alaska and Japan. These ships are still engaged on this route.

In 1963, Technigaz, a subsidiary of Gazocean with Gaz de France, was founded to progress the earlier work into membranes conducted by Lorentzen. The original aluminium lining and wood insulation was replaced by stainless steel and PVC foam respectively. The system was fitted to the first LNG membrane tank ship, the 630 cu. metre *Pythagore* built at Ateliers et Chantiers du Havre, in 1964. The reduced capacity of this ship negated her use for commercial purposes.

Conch International and Gazocean formed the Conch Ocean and Transgaz Services in 1967 to combine, refine and redesign the Conch and Technigaz Membrane systems. This system utilises the Technigaz stainless steel membrane primary barrier and the Conch plywood secondary barrier and balsa wood insulation. This system named the Technigaz Membrane System was first fitted to the 50 000 cu. metre LNG tanker *Descartes*, built at Chantiers de l'Atlantique de Saint Nazaire in 1971 for the Skikda, Algeria, to Boston route.

Shell's involvement in the transportation of LNG from Brunei to Japan led to the ordering of four 75 000 cu. metre LNG ships to be built with the Technigaz Membrane System at Chantiers de l'Atlantique Saint Nazaire; namely the *Gadinia*, in 1972, the *Gadila* and *Gari*, in 1973, and, lastly, the *Gastrana*, in 1974.

Esso established, in Italy and Spain, an aluminium self-supporting system to be fitted to two 40 000 cu. metre LNG carriers *Esso Brega* and *Esso Porto Venere* built at Italcantieri, Genoa, in 1969. These ships were followed, in 1970, by two more 40 000 cu. metre ships *Esso Liguria* from Italcantieri, and *Laieta* from Astilleras y Talleres del Noroeste at El Ferrol. All these ships trade between Libya and Italy/Spain.

The conception of the spherical tank design was undertaken concurrently at Technigaz and Moss-Rosenberg, who are part of Kvaerner Group, with the Technigaz system being fitted to the 4000 cu. metre LNG carrier *Euclides* built in 1971 at Ateliers et Chantiers du Havre. This ship is notable for the fact that it is the first LNG ship to be built without a secondary barrier. The first Moss-Rosenberg spherical tanks followed in 1973 with the 29 000 cu. metre *Venator* and the 87 500 cu. metre *Norman Lady*, at present trading between Abu Dhabi and Japan.

The beginning of the 1970s saw the development of two more spherical tank designs; from Sener at Bilbao, and the Chicago Bridge Company. In 1974, Hitachi fitted a CBI sphere to the 1100 cu. metre experimental LNG carrier *Sankyo Ethylene Maru* together with a 9 per cent nickel self-supporting tank, and, in 1977, a Sener sphere was fitted to the 5000 cu. metre *Sant Jordi*.

The end of the 1960s saw the development of a multi-lobed horizontal cylindrical system from Liquid Gaz Anlagen fitted to the 2725 cu. metre *Melrose* from H. Brandt KG, Oldenburg, in 1971. Four more small ships followed from the same shipyard; namely the *Heriot*, in 1972, the *Anna Schulte* and *Sophie Schulte*, in 1973, and, finally, the *Lissy Schulte*, in 1974.

In 1970, the El Paso Natural Gas Company became involved in the transportation of LNG from Arzew to terminals near Baltimore and Savannah and initiated orders for a fleet of nine 125 000 cu. metre gas ships to be built, of which three have been built to the Gaz Transport system; the *El Paso Paul Kayser*, in 1975, the *El Paso Sonatrach*, in 1976, and the *El Paso Consolidated*, in 1977, from Chantiers France Dunkerque, and one with the Technigaz Membrane system from the Newport News Shipbuilding, the *El Paso Southern*, in 1977. The remaining five ships, on order, are to be built with the Technigaz system (2) and the recently developed Conch 2 Membrane System (3).

The recent years have seen the establishment of the major containment systems with eight ships built with Moss-Rosenberg tanks, the largest being the 126 750 cu. metre *LNG Aquarius* at General Dynamics in 1977, four Technigaz Membranes, the 125 260 cu. metre *Mostafa Ben Boulaid* being the largest from Chantiers Naval de la Ciotat, and eight ships built with the Gaz Transport Membrane System, with among the largest being the 129 500 cu. metre *Edouard L D* from Chantiers France-Dunkerque in 1977, and the 131 000 cu. metre *Methania* from Boelwerf in 1978.

The 1970s have seen the evolvement of a number of new systems—from Gaz Transport in association with McDonnell-Douglas, on one hand, and Pittsburgh des Moines on the other, Technigaz with the Mark II, Mark III and LPG systems, Linde with a multi-vertical cylindrical system, Liquid Gas Anlagen's Zellentank system, IHI flat tank system, Astano's membrane system, Ocean Phoenix's multi-lobed tanks, and, the largest to date, a 330 000 cu. metre design using multi-vertical cylinders from Verolme.

5 THE IMCO CODE AND LR

In November 1975, the ninth Assembly of the Inter-Governmental Maritime Consultative Organization (IMCO) adopted the Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (Resolution A.328 (IX)).

The intention of this code is to provide an internationally agreed standard for the design, construction and operation for the safe carriage of liquefied gases in bulk. This is achieved by describing the design and constructional features of the ships involved in such carriage and the equipment they should carry, in order to minimize the risk to the ship and its crew, and to the environment, having regard to the nature of the products involved. The adoption of these regulations will thereby greatly ease the acceptance of a foreign flag ship into any port and also ensure the safety of the port personnel and the surrounding population during the ship operations of loading and discharging cargoes.

The Code was prepared by the IMCO Sub-Committee on Ship Design and Equipment. This Sub-Committee comprised members from Belgium, Canada, Denmark, Federal Republic of Germany, Finland, France, Italy, Japan, Liberia, Netherlands, Norway, Poland, Sweden, Union of Soviet Socialist Republics, the United States and the United Kingdom. The preparation of the Code was also contributed to by the International Electro-technical Commission (IEC), International Chamber of Shipping (ICS), International Association of Classification Societies (IACS), and the International

Superphosphates Manufacturing Association/European Nitrogen Producers' Association (IMSA/ENPA).

The Code applies to new ships:

(i) for which the building contract is placed after 31st October, 1976; or

(ii) in the absence of a building contract, the keel of which is laid or which is at a similar stage of construction after 31st October, 1976; or

(iii) the delivery of which is after 30th June, 1980; or

(iv) which have undergone major conversion:

  (1) for which the contract is placed after 31st October, 1976; or

  (2) in the absence of a contract the conversion of which is begun after 31st October, 1976; or

  (3) which is completed after 30th June, 1980.

The provisions for existing ships that are not categorized under the conditions for new ships in the Code are stipulated in the IMCO Code for Existing Ships Carrying Liquefied Gases in Bulk (Resolution A.329 (IX)).

The major concern of the Code was the formation of regulations to cover the cargo containment for the liquefied gas to minimize the possible occurrence of any release of gas and the incurrent hazards. The responsibility for drafting proposals for the sections of the Code relating to cargo containment systems, piping systems, pressure vessels, materials of construction and non-destructive testing, was assigned to the International Association of Classification Societies (IACS) due their expertise and experience in this field. After consideration by the IMCO working party which was formed to study proposals for inclusion in the Code, the majority of the IACS recommendations were adopted and form the substance of Chapters IV, V and VI.

In 1975, the Society introduced its Rules and Regulations for the Construction and Classification of Ships for the Carriage of Liquefied Gases in Bulk incorporating the IMCO Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk. These Rules have been developed to ensure the maximum compatibility with the IMCO Code. It should be noted that the Society has had Rules and Regulations for Ships for Liquefied Gases since the early Sixties and that these Rules bore a close resemblance to the present Rules in terms of philosophy for safety.

The Rules recognize that the failure of some ship components could lead to cargo tank damage and then result in an uncontrolled release of liquefied gas. Such a release could cause the cargo to evaporate and disperse and, in some cases, cause brittle fracture to the ship's hull. It is the Society's intention to minimize this risk so far as practicable, based upon the present technology and knowledge.

The incorporation of the Code in the Rules has been supplemented by paragraphs prefixed by 'LR' that have been included to expand the necessary requirements for classification. It should be noted that certain aspects of the Code, although set down in the Rules, are not classification requirements, such as Chapter II (Ship Survival Capacity and Cargo Tank Location) and Chapter XVIII (operating requirements) and this is stated in the preamble of the Rules.

The recommendations of the Code come under continual review by the Working Groups involved and amendments to the Code are drafted for incorporation in the Code.

6 CONTAINMENT SYSTEMS

It is important to understand the categories into which cargo containment systems may be divided for the purpose of classification before a detailed examination of the different systems available to the shipowner is undertaken.

The division of these systems has been determined by such factors as the configuration of the containment structure, the carriage temperature, the design vapour pressure, the interaction of the cargo tank with the adjoining ship's structure, and, in the case of independent tanks, the prescribed method of scantling derivation.

The carriage of liquefied gas is envisaged in one of the following containment tank types:

(i) Integral

(ii) Membrane

(iii) Semi-Membrane

(iv) Internal Insulation, type 1 and 2

(v) Independent, type A, B and C.

The integral tank, Fig. 3A, as the name implies, forms a structural part of the ship's hull and, as such, will be influenced by hull girder stresses and local loading. This configuration is designed for a carriage temperature having a minimum value of -10°C.

The membrane tank, Fig. 3B, is categorized as a non self-supporting tank consisting of a thin layer (membrane) which derives its support from the adjacent hull structure via the interconnecting insulating material.

The semi-membrane tank, Fig. 3C, is defined as a non self-supporting tank when subjected to a loaded condition with the load being conveyed from the membrane layer to the adjacent hull structure through the insulation. In this arrangement the curved sections of the membrane are unsupported and designed to absorb the thermal expansion and contraction effects inherent in the loading and discharging of cargo.

The internal insulation tank is non self-supporting and consists of a homogeneous or laminated insulation material that is supported by the adjacent hull structure or by an independent load bearing surface. These tanks are further subdivided into type 1 and type 2 internal insulation tank. The type 1, *see* Fig. 3D, is a tank in which the insulation or a combination of the insulation and one or more liners functions as the primary barrier. The type 2 tank, *see* Fig. 3E, is one in which the insulation or a combination of the insulation and one or more liners functions as a primary and a secondary barrier which may be separately distinguished. The liner mentioned in this definition is intended as a thin layer to enhance the fracture resistant properties of the system and not to act as a liquid-tight barrier. It should be understood that these types of internal insulation systems are, at present, under consideration by IMCO.

In the preceding tank types, the design vapour pressure is not normally to exceed 0.25 bar unless the hull scantlings have been increased accordingly and the strength of the supporting insulation, where appropriate, has been established. In this instance, a higher vapour pressure may be accepted provided it does not exceed 0.7 bar.

The independent tank, Fig. 3F, is self-supporting and does not form an integrated part of the ship's structure or contribute to the hull strength. These tanks are classified into type A, B and C independent tanks.

The type A independent tank is designed using classical ship structural analysis procedures. Where these tanks are primarily constructed of plane surfaces (gravity tanks), the design vapour pressure should not exceed 0.7 bar.

The type B independent tank is designed using model tests, refined analytical tools and analysis methods to determine stress levels, fatigue life and crack propagation characteristics. Where the tanks are primarily constructed of plane surfaces (gravity tanks), the design vapour pressure should be less than 0.7 bar.

The type C independent tank, which is also referred to as a pressure vessel, is a tank that is designed to pressure vessel criteria.

The containment systems available today, detailed in the Appendix to this paper, can be grouped into systems that are currently in service in ships and those that have been proposed but are yet to be specified for application to a particular ship. These systems are:

(i) in service:
- Bridgestone semi-membrane
- CBI spherical independent
- Conch independent
- Esso independent
- Gaz de France cylindrical independent
- Gaz Transport membrane
- Hitachi Zosen/Esso independent
- LGA horizontal cylindrical independent
- Moss-Rosenberg spherical independent
- Sener spherical independent
- Shell LPG internal insulation
- Technigaz membrane
- Technigaz spherical independent

(ii) proposed:
- Astano membrane
- Conch 2 membrane
- Gaz Transport/McDonnell-Douglas membrane
- Gaz Transport/Pittsburgh des Moines independent
- IHI semi-membrane
- Linde cylindrical independent
- LGA Zellentank independent
- Ocean Phoenix multi-lobed independent
- Shell LNG internal insulation
- Technigaz Mark II membrane
- Technigaz Mark III membrane
- Technigaz LPG membrane
- Verolnave cylindrical independent

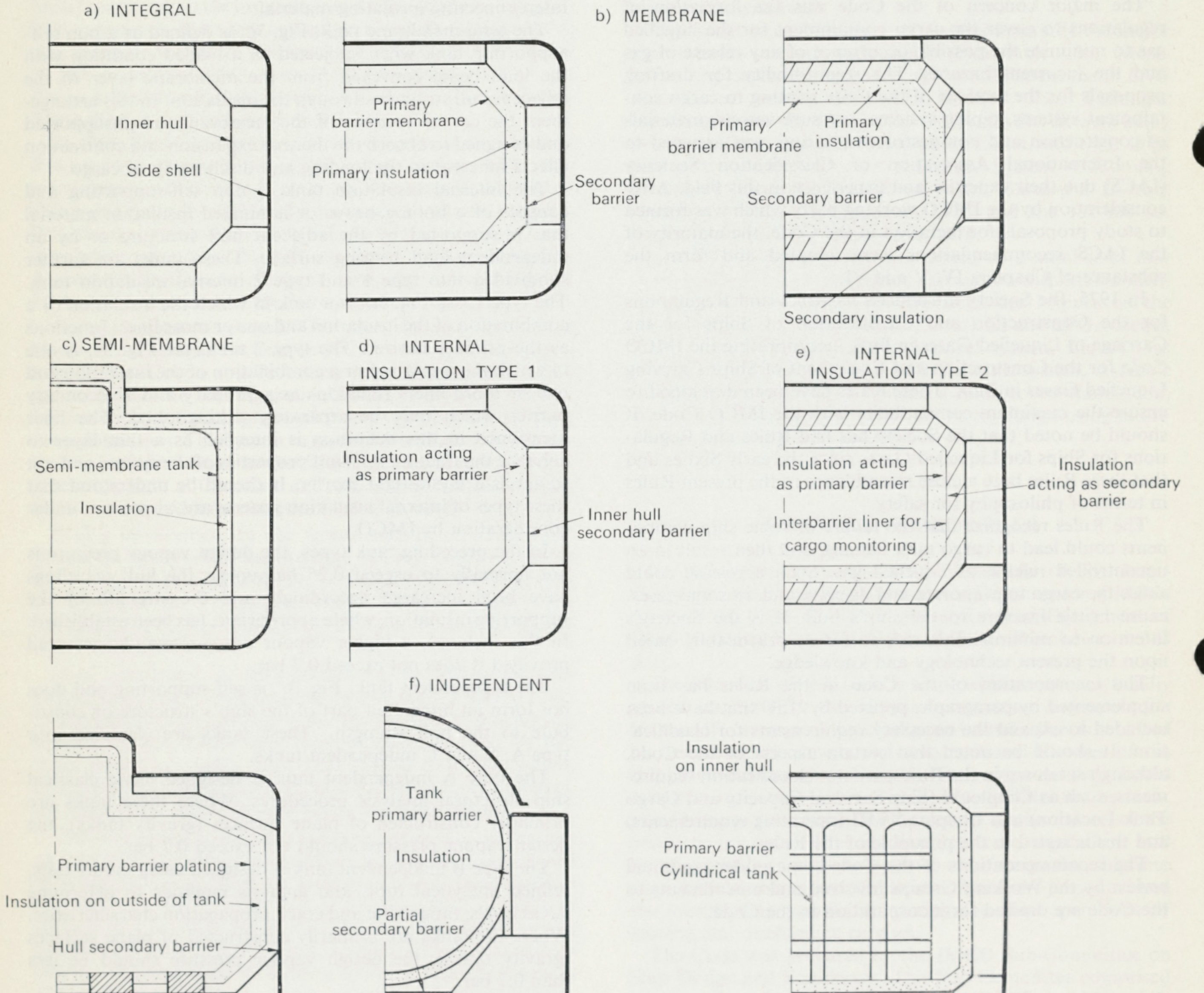

Fig. 3

A typical section for the various containment tank types.

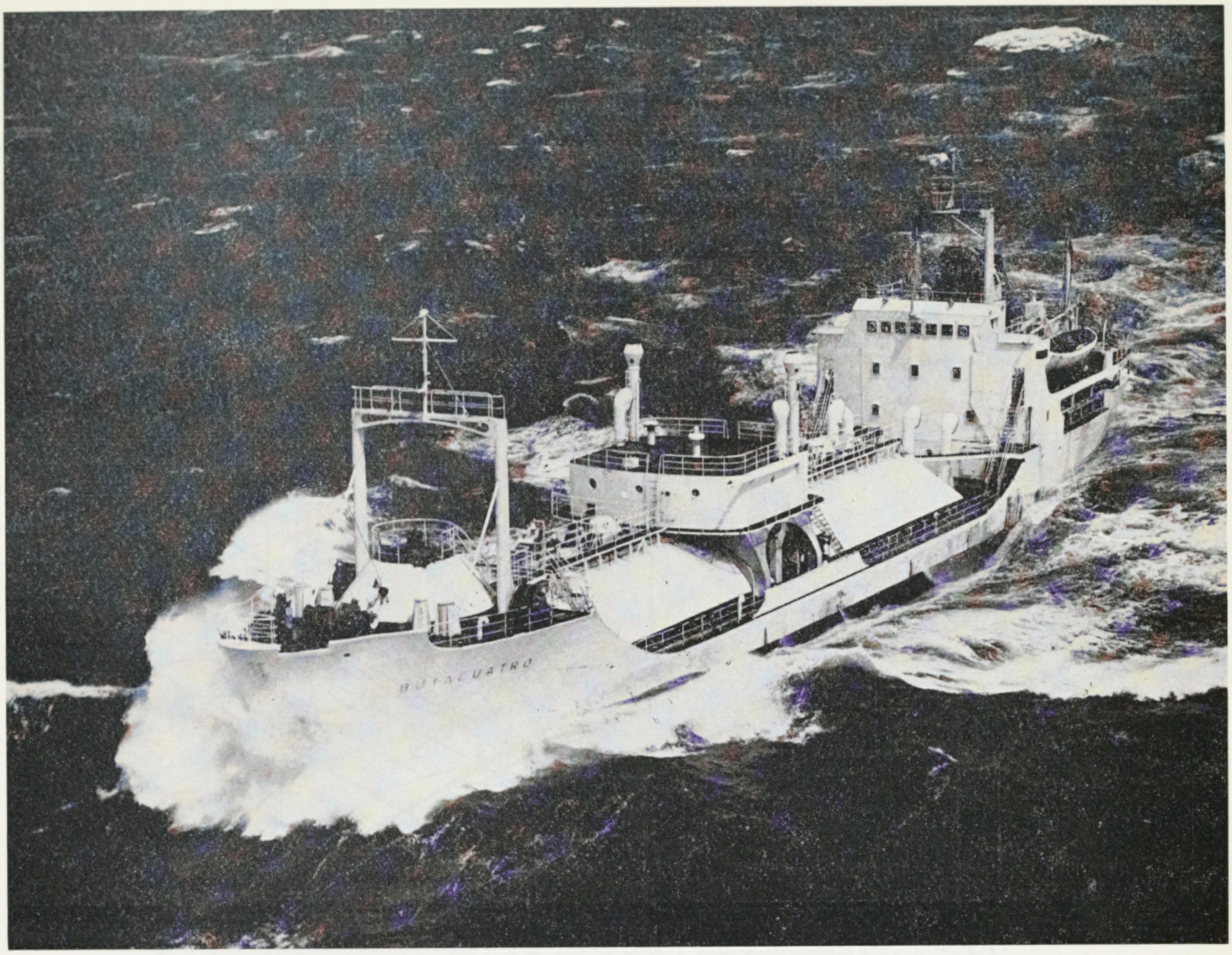

Plate IV. The 2000 cu. metre *Butacuatro* fitted with spherical and cylindrical independent tanks.

7 SYSTEMS APPROVAL BY LR

The approval of liquefied gas containment systems from the strength aspect is generally considered by the Society in three stages, which have been conceived to evaluate the system during its devlopment from the initial design concept to the actual use for the containment of liquefied gas in a particular ship.

Systems which are submitted to the Society, will be subjected to the following approval stages in sequence:

(i) Approval in Principle.
(ii) General Approval for Ship Application.
(iii) Approval for Particular Ship Application.

The systems will be considered after their initial concept, when the design configuration and the materials to be employed, have been submitted.

The Society assesses the configuration of the containment system with regard to compliance with requirements for primary and secondary containment and also the monitoring systems. These arrangements are considered together with the basic particulars of the component materials for compatibility, mechanical and fatigue properties and also insulation properties as applicable. When the Society is satisfied with the feasibility of the system then the designation 'Approval in Principle' may be granted.

The next progression in the approval of the system depends primarily on the type of containment under consideration.

In the case of independent tank systems, this stage involves a feasibility assessment of the tank using mathematical simulations in order to study both the tank and its interactive response with the ship.

Membrane and internal insulation systems, that derive their support from the ship's hull, have to be subjected to an intensive testing programme for the individual components, sections of the system and large scale, (complete tank), tests.

The individual testing of the component materials, which are being used in this application for the first time, are necessary to determine such specifications as physical and mechanical properties, ageing, permeability, fatigue characteristics, adhesion, compatibility with cargo/seawater and other materials, gas freeing rates, etc., at both ambient temperature and the cargo carriage temperature.

After individual testing, the component parts require to be tested as a composite system. This involves the use of test panels that comprise a section of the containment system attached to a plating base that is representative of the stiffness and configuration of the ship's inner hull. This will verify the compatibility of the material and also determine the fatigue life of the system when subjected to the projected loadings associated with liquefied gas carriage.

The last part of this testing programme will be the large scale testing of the system, utilizing a tank design which incorporates a design configuration typical of that proposed to be employed on a future gas ship.

When these parts, either physical or mathematically simulated, are concluded to the Society's satisfaction, the system may be granted 'General Approval for Ship Application'.

The final stage in the approval procedure is completed when the system is proposed for a particular ship. In this instance it is only required to be confirmed that the design parameters used in the verification for 'General Approval for Ship Application' are not exceeded so that 'Approval for Particular Ship Application' may be designated.

The approval status of the submitted containment systems is as follows:

(i) 'Approval in Principle'

Hitachi Zosen/Esso

Ocean Phoenix

Astano.

(ii) 'General Approval for Ship Application'

Moss-Rosenberg

Sener 9% Ni spheres

Gaz Transport/McDonnell Douglas

Conch 2

Technigaz Mark II and III

Shell Puf for LPG

Technigaz LPG

(iii) 'Approval for Particular Ship Application'

Conch

Gaz Transport

Technigaz

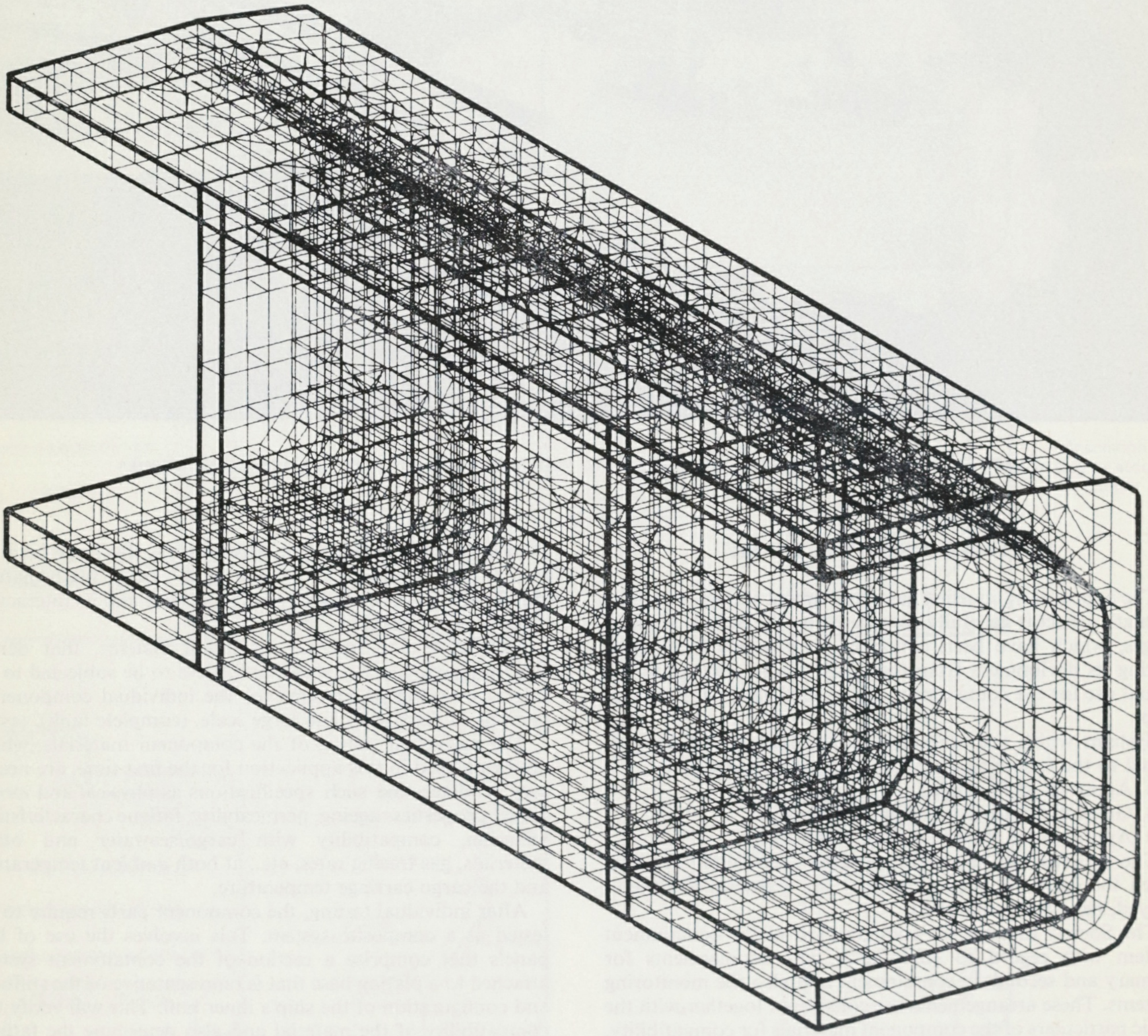

Fig. 4

Finite plate element model of part of the cargo tank region for a 59 000 cu. metre liquefied gas tanker.

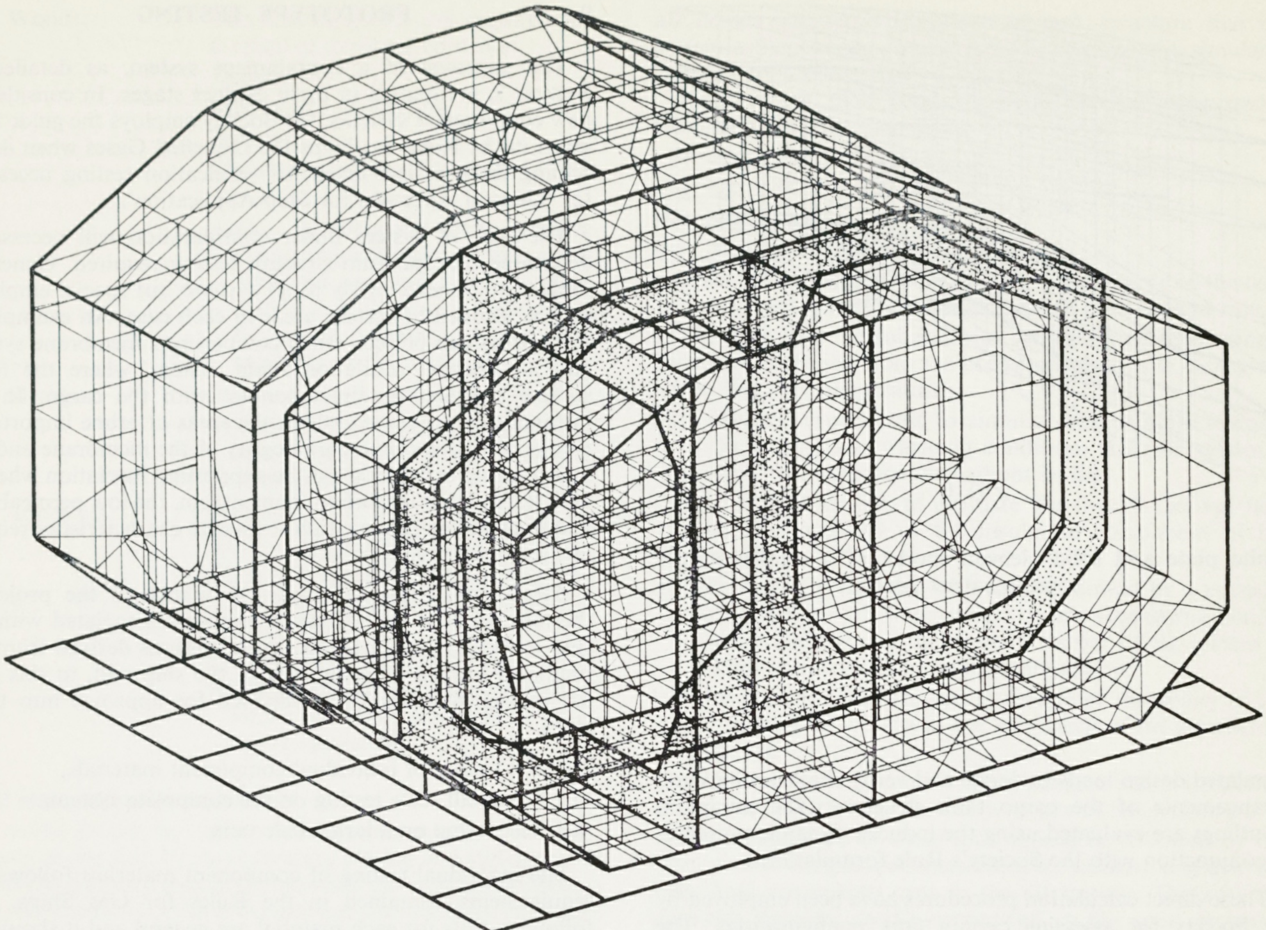

FIG. 5
Finite plate element model of two half cargo tanks for a 59 000 cu. metre liquefied gas carrier.

8 DESIGN CRITERIA

The primary concern in the evaluation of the structural configuration inherent in the type of containment system under consideration is the ability of the containment material and the supporting structure to withstand the design loads and their combination envisaged during the lifespan of the ship.

The containment structure together with its supports and fixtures, where relevant, should be designed to take into account the following loads:

- Internal pressure
- External pressure
- Dynamic loads due to the motion of the ship
- Sloshing loads
- Thermal loads
- Loads corresponding to ship deflection
- Tank and cargo weight with the corresponding reactions in way of supports
- Insulation weight
- Loads in way of towers and other attachments.

The pressure loadings utilized in the derivation of the containment structure scantlings results from the effects of design vapour pressure and the internal liquid pressure. The internal liquid pressure is created by the acceleration of the centre of gravity of the liquefied gas caused by the motion of the ship and gravitational force. The formulations governing this combination of pressures are detailed in the Society's Rules for Liquefied Gas Ships incorporating the IMCO Gas Code.

The dynamic loads are based on long-term analysis of ship motions over an assumed design life of twenty years which corresponds to approximately 10^8 wave encounters. These loads include the effects of pitch, heave, roll, yaw, sway and surge to establish the components of vertical, transverse and longitudinal acceleration acting on the cargo at its centre of gravity.

The carriage of liquefied gas at partial tank fillings incurs the possibility of damage to the containment system resulting from the sloshing loads induced when the natural frequency of the cargo synchronizes with the motion of the ship, and this requires to be assessed if partial fillings are contemplated.

Where the liquefied gas is to be carried at temperatures below $-55°C$, the transient thermal loads should be considered for the transition from the temperatures associated with the cargo tank in the void state to that experienced in the fully loaded condition, as this may give rise to significant thermal stresses. Steady state thermal loads should also be considered in possible regions of high stress. Examples of this would be in the vicinity of support arrangements and at the secondary barrier in a condition of primary barrier failure bringing the cargo into direct contact with the secondary barrier.

Structural analysis techniques are employed using the

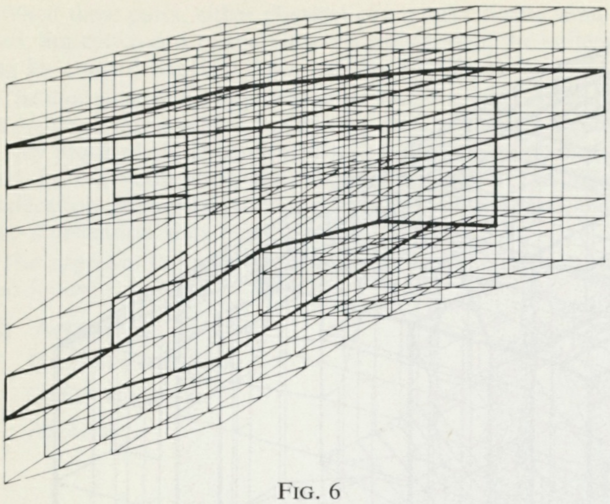

FIG. 6

Finite plate and solid element model of a section of the topside ballast tank.

stipulated design loads to derive and verify the scantlings and arrangements of the cargo tank structure. The minimum scantlings are evaluated using the induced dynamic pressures in conjunction with the Society's Rule formulations.

These direct calculation procedures have been employed by the Society for assessing certain tank configurations. The finite element plate models shown in Figs. 4 and 5 represents part of the cargo tank structures of two 59 000 cubic metre liquefied gas ships. The first idealisation (Fig. 4) simulates the structure of a double hull gas tanker which has been designed to incorporate a specific internal insulation system. The main importance of this analysis other than to evaluate the integrity of the supporting structure was to indicate the in-plane stresses in the inner hull plating and therefore to enable the determination of deflection magnitudes for the supporting plating. These criteria are used to form a basis for the system's Approval for Particular Ship Application. The second model represents an independent tank design, where the cargo tank plating acts as the primary barrier, and includes the supports and the ship's double bottom structure to enable an investigation into the interaction between the ship and the cargo tanks. These evaluations were concluded with a detailed structural and buckling analysis of the cargo tank structures.

In both the analyses mentioned, the effect of the deflection of the ship's hull under the design and service loading conditions was taken into account at the boundaries of the models as, for relevant results, the idealisations were limited to one tank and two halves, in the case of the gas tanker, and to half a tank and half a tank with the gas carrier.

The finite element procedure has also been utilized to determine the extent of special quality steel deck plating into the area of the topside ballast tanks using heat flow analysis for an independent tank design. This analysis considered the primary barrier plating to be breached and the cargo at -48°C to have filled the interbarrier spaces and be in contact with the deck at centre and the inner surface of the topside tank plating (*see* Fig. 6).

The extent of the structural analysis required for each containment type is dictated by the Society's Rules but the aforementioned analyses procedures are generally implemented.

9 PROTOTYPE TESTING

The approval of a containment system, as detailed in Section 7, is attained in three distinct stages. In considering new containment systems, the Society employs the guide lines given in the Rules for Ships for Liquefied Gases when determining the type and extent of verification testing necessary for 'General Approval for Ship Application'.

The type of system under consideration will necessarily determine the optimum strength testing required. Generally these requirements apply to all systems but special emphasis will be attuned to certain areas in each case. An example of these areas can be seen when comparing a membrane system and an internal insulation foam system, where the foam surface comes into direct contact with the cargo. In the instance of membrane system, the areas of prime importance would be to determine the integrity of the membrane and the load bearing capabilities of the supporting insulation whereas with the internal insulation foam system, the low permeability and the fracture propagation resistance characteristics require primary consideration.

All systems must be shown to withstand the projected thermal loadings and dynamic pressures associated with the ship and cargo under the design conditions derived from the predicted lifespan and motions of the ship and, to this end, the testing procedure is subdivided for approval into three steps.

(i) the testing of individual component materials,
(ii) the small scale testing on the composite system,
(iii) the testing on a large scale tank.

The individual testing of component materials follows the requirements contained in the Rules for Gas Ships. The following tests for each material are general and it should be understood that special emphasis may be paid to one test depending on the usage of the material. It should also be noted that the inclusion of such engineering materials that have been well proven in service may preclude the necessity to fulfill certain of the following stipulated tests.

(i) Foam materials:
- Density,
- Mechanical properties,
- Ageing,
- Cellular structure and size,
- Static fatigue (creep rate),
- Adhesion/cohesion properties,
- Chemical compatability with cargo and other contact materials,
- Gas freeing characteristics,
- Fatigue properties,
- and, in the case of internal insulation foam or laminated foam tanks, the materials defect propagation resistance.

(ii) Plastics materials: (i.e. GRP)
- Mechanical properties,
- Ageing,
- Creep rate,
- Adhesion,
- Chemical compatibility with cargo and other contact materials,
- and, Fatigue properties of materials and joints.
- If the materials are used for the primary or secondary membrane then Defect propagation resistance, Lap tightness and Permeability tests will also be required.

(iii) Wood: The following tests are required for a range of moisture contents:
Density,
Mechanical properties,
Ageing,
Chemical compatibility with Cargo,
Adhesion,
Ability to withstand cyclic loading during ship's lifespan depending on proposed use, and, for laminated woods (i.e. plywood) when used for cargo containment, the permeability of the material.

(iv) Metals: Mechanical properties,
Chemical compatibility with cargo, and fatigue properties of welded connections.

(v) Adhesives: Density,
Mechanical properties,
Chemical compatibility with cargo, saltwater and other component materials,
Fatigue properties,
Bonding strength of component materials and also material to hull where applicable.

Small scale composite model tests

A model should be constructed to represent the local hull stiffness of the ship by incorporating plating and stiffening of such projected scantlings as to assimilate the local panel deflections that result from the hull loadings, and insulated with the system for which the component materials have been individually tested.

This composite model is to be subjected to cargo and ballast loadings with the temperature at the primary barrier as per the predicted temperature during normal operational service. The design loads are detailed in the 'Rules for Gas Ships' and are based on a probability level of 10^{-8} corresponding to one occurrence in the ship's life span of twenty years.

The general testing programme to analyse the system's response to fatigue loading requires the following applications to the composite model:

(i) Cyclic loadings to represent both the cargo and ballast pressures predicted and also the temperature changes on and within the system during the lifespan of the ship.
(iii) The effect of a fracture on the containment system supporting plating to ensure that no critical failure to the system will be instigated during the ship's life. This is also to show that any ingress of water ballast, under dynamic pressure, will not prove detrimental to the system.
(iv) As stated in the Rules, it is required to prove the integrity of the secondary barrier in the event of primary barrier failure to allow for a stated period of 15 days taking into account the predicted 10^{-8} load spectrum.
(v) The verification of the membrane tightness, where applicable, and the development of quality control procedures to so ensure.
(vi) The response of the system to vibration excited by the dynamic loadings in a seaway and any other mechanical excitation sources that may be present.

Large tank tests

The third stage of prototype testing requires the construction of a test tank to be lined with the insulation system that will be fitted to prospective ships. This tank must incorporate all design geometric variations of tank structure that the system will encounter to determine its behaviour in simulated service conditions.

The average tank should include the following design features in its structure:

(i) tank side
(ii) tank top
(iii) hatch corner
(iv) transverse bulkhead connection
(v) an anchoring device to the strength member of the containment system located at the top, bottom, and side.

The tank is to be subjected to the following tests using a testing fluid chosen from the projected cargo lists having the lowest carrying temperature:

(i) Thermal cycling test to simulate the cooling, loading, discharging and warming conditions that the system is likely to experience throughout its life.
(ii) Heat balance test to evaluate the overall thermal heat transfer property of the insulation component of the system.
(iii) Pressure Cycling test with cargo followed by a pressure cycling test with waterballast on the supporting plating whilst maintaining the primary barrier of the system at cargo temperature by vapour circulation.
(iv) Insulation movement test to determine the ability of the insulation to withstand the movement of the supporting plating.
(v) Erosion test to examine the resistance of the insulation primary surface to fluid flow at service temperatures.

The culmination of these tests should be followed by the extraction of sample specimens from the insulation system for individual component tests in the laboratory. The sites for specimen removal are to correspond to the areas at which repair work tests are to be initiated. The tank should be re-subjected to the testing programme after repairs have been accomplished to establish the integrity of the repair procedure.

The testing requirements outlined in this chapter are general in nature and the Society will allocate specific additional tests after 'Approval in Principle' has been granted should the configuration of the system so warrant.

10 QUALITY CONTROL

The term 'quality control' means all things to all people with the extent being dependent on the need. Quality control is not a science, however, it encompasses the most difficult of all tasks, the verification of the actions of human beings in their implementation of specific tasks of work.

Liquefied gas containment systems require to have a consistently high confidence level of manufacture and installation.

To standardize the basic parameters for the systematic control in the various component stages in the construction of a containment system, the IMCO gas code and the Society's Rules for Ships for Liquefied Gases make provision for procedure tests, production and non-destructive testing as well as the testing at the post constructional stages.

In addition the development of new types of systems is required to be accompanied by the conception of a quality control procedure which will ensure the components of the 'as fitted shipborne' system to be the same as that used in the system proving trials.

Quality control, it should be appreciated, is not limited to defining parameters but is, in fact, the active control ensuring that the various constructional verification parameters are met and involves the Society's Surveyors and the Shipbuilders in close co-operation. Quality control, while seemingly non-productive in industrial terms, is, in its necessary application

to gas ships, productive in ensuring a higher confidence level and safer operation of the ships.

So where does quality control begin with containment system? In essence, it begins with the assessment of the basic component materials of the system verifying their fitness for the purpose intended. Welding and joining processes are assessed for integrity by means such as ultrasonics, radiography and leak testing. Composite structures are verified for constructional consistency by structural pressure testing. This theme of safety is extended when carrying out repairs to both the ship and its containment system and even modifications of the most minor nature require the most careful control.

The whole aspect of quality control in the construction of gas ships will, due to its extent, dramatically affect the production procedures, normally associated with a shipyard in the construction of normal ship types. The need for laboratory facilities for carrying out testing on samples, storage facilities for fabrication units, procedures for repair and reassessment of repaired units, dictates extensive forward planning. The economic effects on production must bring pressure to bear on arguments as to the strict necessity for the continuing stringency of these controls, with arguments being made for sample testing and confidence levels obtained. This, however, is to be resisted in view of the hazards involved in the operation of the systems.

11 LEAK DETECTION

It should be realized that the basic design philosophy for containment systems for the carriage of cryogenic cargoes revolves around the consideration of leak detection. All containment systems must, necessarily, be designed for 'leak before failure' in that any leak of cargo, in whatever amount, from the primary containment, will not result in the complete failure of the system. Indeed the IMCO Gas Ship Code and the Society's Rules for Gas Ships are based on this concept.

Whilst comprehensive analysis, practical testing and extensive quality control can considerably minimize the possibility of failure to the containment system, its probability must be accepted. The human factor, in the construction of the ship, the installation of the cargo containment system itself and their operation, still prevails. Having, therefore, conceded this, the provision of a detection system, to announce any cargo leakage which detracts from the safety of the ship and allow sufficient time for appropriate action to be taken, becomes necessary.

The requirements of the Rules for Gas Ships regarding gas detection and gauging are contained in Chapter XIII of the Rules. In essence, these state that means should be provided to indicate the level, pressure and temperature of the cargo during normal service conditions. Further the details for the instrumentation for gas detection in the event of a failure to the containment system are given.

Temperature indicating devices should be fitted to the cargo tank, with a minimum of two, one at the top and one at the bottom. In the case where the cargo is carried at temperatures below $-55^\circ C$ where a secondary barrier, other than the outer hull, is required, temperature indicating devices should be incorporated within the insulation of the containment system or on the hull structure adjacent to the containment system. These devices should provide readings at regular intervals and give audible and visual warnings should the minimum permissible temperatures be approached.

Permanently installed gas detection equipment should be installed to monitor the enclosed spaces in the cargo area where vapour may accumulate including hold spaces and interbarrier spaces for independent tanks other than tank type C. This equipment should be capable of sampling and analysing from nominated sampling head locations sequentially at intervals not exceeding thirty minutes.

The gas detection unit is usually situated in the cargo control room and designed to give an audible and visual alarm should the gas concentration in the interbarrier space exceed a chosen level normally taken as 30 per cent LEL (lower explosive limit). The sampling points are positioned according to the density of gas carried. In the case of ammonia, the sampling point is situated at the top of the tank and, with propane and butane, the sampling point is located at the bottom of the tank. This equipment may possibly be used to detect water in the interbarrier space on the basis of a 'no flow alarm' i.e. no flow of gas through the detectors.

Duplicate equipment is normally provided on ships to cater for any malfunction, along with portable detecting equipment for testing spaces prior to entry.

12 SYSTEMS FAILURE

In carrying liquefied gases by sea, the occurrence of a critical failure to the containment system would endanger the ship and prove a matter of grave concern to all.

As is the case with most ships, the ships built for the carriage of liquefied gases are subjected to the normal working abuse associated with the environment, the handling by tugs and the berthing at quay sides. In accepting this, a philosophy which envisages low energy impacts, affecting the integrity of the ship's outer hull, has emerged. In this respect, the location of the cargo containment tanks, inboard from the ship's side and above the ship's bottom, is a primary requirement.

Ships are, of course, buoyant responsive bodies, which are subjected to the various dynamic motions imposed in a seaway. These, in addition to the thermal cycling loads, apply a dynamic aspect of load directly to the primary containment tank.

As the consequences of failure leading to the uncontrolled release of refrigerated liquefied gas are highly undersirable for the survival of the ship, and also therefore from environmental aspects, a further design requirement is the provision of an emergency secondary means of containment to provide the ship with a 15-day design period to safely discharge its cargo.

With the foregoing in mind, it will be appreciated that failure is envisaged as a fundamental design philosophy in both the hull, due to the general working of the ship, and in the primary cargo containment system although not both at the same time. This is emphasized to highlight the necessity for the continuing maintenance of both the ship and the containment system in view of the danger in the line of thought which views the ship as being a separate unrelated entity from the containment system.

From this standpoint, it would be perfectly true to surmise that any failure to the ship which affects its seaworthiness does indeed endanger the cargo containment system.

This paper is, however, directed primarily at means for the immediate containment of the cargo and it is this aspect at which this chapter is directed.

In considering the statistics available, it is surprising that these ships, which at their conception, it must be remembered, were employing new concepts in shipbuilding, have suffered relatively few failures.

Relating to incidents and damages which have been recorded as having been experienced by the cargo containment systems on these ship types, it can be concluded that these can generally be said to occur due to load concentrations, fatigue or maloperation and, perhaps, combinations of these.

Where independent tanks are used for cargo containment, load concentrations are created by the differential stiffness of the ship and the cargo tanks and result in a bias of load to certain of the cargo tank supports. This distribution of load

is dependent to a great extent on the loading condition of the ship with the major proportion of load to the double bottom at the ends of the hold spaces whilst the ship is fully loaded.

An important factor, which affects the level of stresses experienced in the ship's bottom structure, is the ability of the cargo tank seatings to distribute the loadings. In cases where cargo tanks are situated on wood chocks which are located directly on the ship's inner bottom, the incurred stress concentrations have resulted in the occurrence of fractures in the floors and inner bottom platings. In addition to saturating the insulation with ballast water, the integrity of the secondary barrier under these conditions is also affected.

In such cases, where the design permits, it is considered that the only sure way of providing a remedy to this situation is by fitting steel seats with webs designed so as to distribute load over a wide area. There are, of course, cases where the design does not permit such modification, particularly where the cargo tanks are located on the tank top immediately above the double bottom, in which case the re-distribution of loading would have to be provided by additional stiffening to the inner bottom within the double bottom space.

This aspect of cargo tank load distribution has been long known and this is reflected in the continuing integrity of the double bottom primary structures in the many ships in service today.

Today's computer facilities do enable predictions to be made of the loadings to be experienced on the cargo tanks, their seatings and in the double bottom structure of the ship, however, the aspect of good detail design and careful choice of seating material cannot be emphasized enough.

Load concentrations may be caused by dynamic aspects of load and, in particular, to the movement of liquids in slack tanks. An example of this, resulting in damage, occurred in 1969 to a 71 500 cu. metre gas tanker employing a membrane system, where a cable tray was destroyed by the generated forces and parts of this dislocated tray perforated the primary membrane. Similarly, in 1971, another ship fitted with the same system was found with the primary barrier boxes and membranes deformed in No. 1 tank with the loss of perlite insulation in the most severe regions where the membrane was torn. In both cases, the secondary barrier remained intact.

Failures of this nature led, in the case of membrane systems, to the adoption of limits on permissible filling levels with fillings between 20 and 90 per cent being generally not permitted. As in the case of membrane systems, internal insulation tanks, if partly filled, are susceptible to large areas of free surface which enables the generation of cargo impact loads of high magnitude. In this respect, it is understood a recent infringement of restricted filling limits on a ship employing a foam internal insulation system has resulted in damage to the primary containment tank; the secondary barrier again remaining intact.

Damage to cargo tanks, by dynamic movement of cargo, is not always confined to conditions where partial fillings are employed. In a recent case, a 125 000 cu. metre LNG tanker, fitted with a membrane system, is reported to have sustained damage in the primary insulation boxes whilst the cargo tanks were alleged to be about 96 per cent full. The damage was reported to be very localized and was only accurately located by the induction of a vacuum in the interbarrier space so as to draw the primary membrane against the damaged plywood boxes.

In addition to damages created directly by cargo loadings, failures resulting from fatigue of the supporting hull structure are also a major concern. In one particular case, involving an independent tank design, the ingress of water into the inter-barrier space caused substantial structural damage to the independent tank during the cooling down period. This again emphasizes the necessity for particular attention to detail design so as to minimize the levels of stress concentrations and, therefore, fatigue failures.

In employing these concepts of containment systems to ships, experience has shown that application procedures may, in view of the scale and location of the applications, be less than ideal. Examples of this being the procedures used for manual welding on certain locations of membrane systems which have resulted in slight consistent cargo vapour ingress into the inter-barrier space which has necessitated, on certain ships, the re-calibration of the sensing equipment.

The functioning of any containment system may be seriously impaired by mal-operation. This has been seen with one membrane system where an over-pressurization of nitrogen in the interbarrier space deformed the primary membrane inwards.

Whilst this chapter is confined to damages relating directly to containment systems, the operation of cargo handling and ancillary equipment can also give rise to problems. An example of this is the accidental deck spillages of nitrogen which in the past has created deck fractures.

It is fair to comment on the successful working of the many types of liquefied gas containment systems fitted in ships and the responsible manner in which the systems are continually improved and updated to reflect both practical and operational difficulties experienced.

13 CONCLUDING REMARKS

The whole question of the carriage of liquefied gas is continually being updated due to the many influences that affect the systems developed for its containment. The primary concern will always be towards ensuring the safety of carriage. To this end, the Society, through its participation with IACS, will consider it to be its role to propose revision of the Rules and Regulations as experience necessitates.

The manufacturers, whilst being guided by these criteria, are influenced by such factors as the availability and cost of the basic materials which comprise their individual systems. For their part the tendency is towards simplification in design and the utilization of new engineering materials without detracting from the safety aspects of the containment.

In the present environment of safety consciousness, the continuing co-operation between the System Manufacturers and the Classification Societies or other Regulating bodies will, it is hoped, continue to maintain and enhance, if possible, the levels of safety attained to date.

14 ACKNOWLEDGEMENTS

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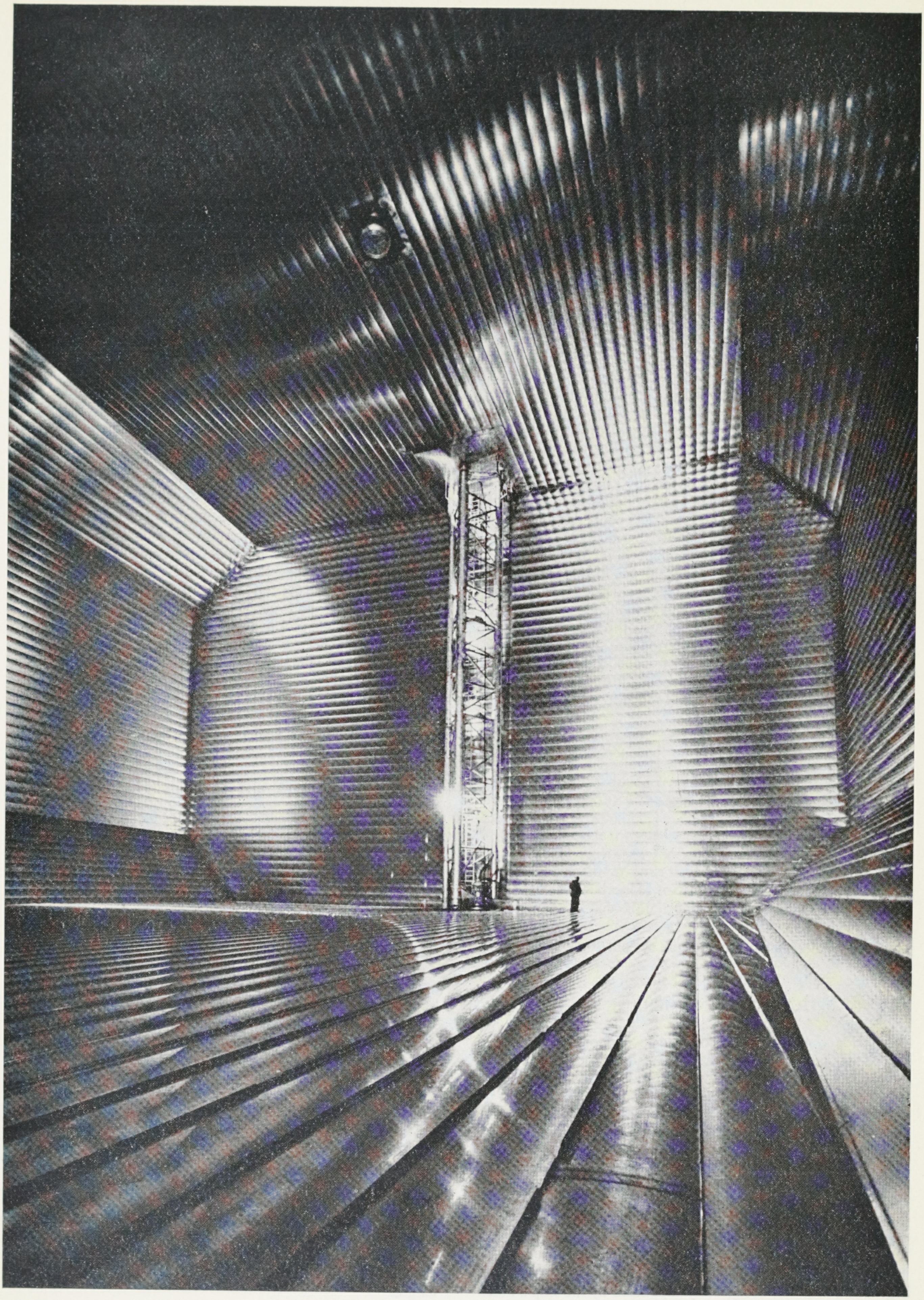


PLATE V. The Gaz-Transport membrane fitted on the 131 000 cu. metre *Methania* undergoing pressure testing.

APPENDIX I

MEMBRANE CONTAINMENT SYSTEMS

1.1 ASTANO MEMBRANE SYSTEM

Astilleros y Talleres del Noroeste, S.A. (ASTANO), have developed a membrane system, the METASTANO 20, for the containment of LNG at −162°C.

A standard panel constructed of two layers of glass-reinforced plastic (GRP) cells, filled with polyurethane foam forms the basis of this membrane system, *see* Fig. 7. The cells are formed by hot pressing of this GRP laminate over moulds consisting of a series of shaped blocks (i.e. male moulds).

The moulds are reversed and withdrawn, when the laminate is cured, leaving a module of open cells. These cells are filled with expanded polyurethane foam, of density 40 kg/m^3, and, then, capped with a subsequent layer of GRP laminate using a mould designed to leave channels in the base of the module. The two layers, forming the panel, are constructed in this manner and joined by epoxy resin. The standard panel now measures approximately 1 metre by 1 metre with 64 cells, and consists of the primary barrier and insulation, and secondary barrier and insulation. The surfaces of the primary barrier and the secondary barrier are described by a three dimensional, alternately concave then convex, surface designed to minimize stresses parallel to the face of the barriers while retaining their high resistant properties normal to the surface. The outer surface of secondary insulation is plane to facilitate adhesion to the flat GRP laminate which by the use of mastic beads is adhered to the inner hull. The panels are designed to overlap each other to form the containment system.

Nitrogen gas is circulated continuously through the channels situated between the primary insulation and secondary barrier and sampled for the detection of leaks. Likewise, in the channels located between the secondary insulation and inner hull, Nitrogen gas is circulated and sampled regularly.

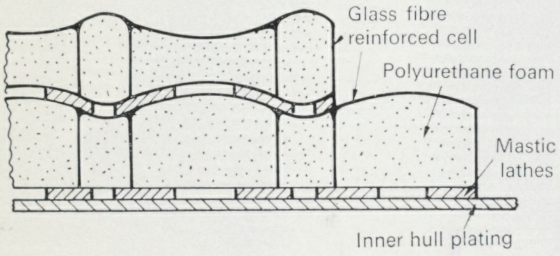


FIG. 7
Astano membrane system.

1.2 GAZ TRANSPORT MEMBRANE SYSTEM

The first system to be introduced to the commercial LNG market by Gaz Transport, employed self-supporting 9 per cent nickel steel cylindrical tanks, a technique used for the 25 500 cu. metre methane carrier *Jules Verne*.

Although transporting methane by sea in this way proved very satisfactory, it was considered that the building of large carriers adopting self-supporting tanks would cost considerably more than those adopting the membrane tank technique, and indeed valuable space would be sacrificed. The experience gained from the construction of the *Jules Verne* was therefore utilized for the development of the *Invar* membrane containment system which was to become one of the most common and reliable systems available.

The Gaz Transport Membrane containment system, *see* Fig. 8, is a modular design fully supported by the ship's inner hull structure. The system consists of a primary and secondary barrier constructed in a 36 per cent nickel steel, called INVAR, with the primary and secondary insulation formed by perlite filled plywood boxes.

The barrier membranes are made up of INVAR strakes 0.7 mm in thickness and 500 mm in width. The insulation boxes are constructed in birch, okoume or beech plywood and strengthened internally by means of longitudinal and transverse plywood partitions. The boxes measure 1.2 metres in length and 500 mm in width with the depth of the box, normally about 200 mm, determined by the 'boil-off' rate required. The plywood utilized is 9 mm in thickness except for the secondary insulation box face where 12 mm plywood is used.

The secondary boxes are secured to the inner hull by means of stud bolts located at the ends of each individual box. Continuous Invar tongues are then fed through grooves located at the half width of each box face. These boxes are separated lengthways at intervals by wooden joists attached by stainless steel straps to the inner hull plating.

The membrane is brought to the hold in a roll 540 mm wide and equal in length to the wall run for which it is intended. The roll is passed through a special jig that flanges the strake edges and feeds the membrane in its final shape along the insulation surface. The flanged edges and tongue are then automatically seam resistance welded.

The primary insulation boxes are arranged against the secondary barrier by means of cryogenic steel channels placed at intervals of 1.2 metres (length of box) and supported on the wooden joists between the secondary boxes. A non continuous Invar tongue with turned edges is stapled to one side of each primary box and a continuous sliding tongue, also with turned edges, engages into it. The flanged strakes are then resistance welded to the protruding tongues in the manner described above. The primary and secondary barrier strakes run the full length and width of the surface without butt joints. They are arranged lengthwise against the bottom, top and sides of the tank and horizontally at the transverse bulkheads.

Each primary and secondary barrier strake terminates on an Invar angle bar, 1.5 mm in thickness, fitted round the perimeter of each transverse bulkhead, and welded to it.

The 36 per cent nickel steel used for the Invar barriers has a low thermal contraction coefficient and eliminates the need for stress relieving surface corrugations in the membrane. This material does not corrode under normal conditions or after preparation during the ship building period. However, corrosion may occur during the tank gas freeing operation if a poor quality inert gas, which has a high dew point and too high a percentage at SO_2 and $NO+NO_2$, is used.

Further, care must be taken to ensure that when tanks employing this membrane are to be left empty for a period of time, or laid up, the space should be filled with inert gas. Alternatively, dry air could be used provided the membrane has been initially prepared as specified by the manufacturer.

The membrane is fully supported by the insulation underneath and therefore the dynamic pressure it can sustain is limited only by the strength of the supporting insulation boxes. An increase in dynamic pressure will only require stiffening of these boxes. This feature will allow the system to be used for larger ships.

The secondary barrier, being of the same material as the primary one, will afford equal strength and be equally effective. The flat nature of the Invar membrane allows automatic welding of about 95 per cent of the membrane joint length.

The ability to rapidly inert or gas free the perlite filled boxes has been proven through service experience.

An important feature of this containment system is the inter-connection of the membranes to the primary and of the secondary insulation which makes gas sampling a relatively simple operation.

As in all membrane designs, the system suffers from being sensitive to mechanical damage. It must be assembled with great care to ensure the membrane is properly supported and alignment of the numerous components achieved. Since the insulation cannot be inspected on a regular basis, a high degree of insulation confidence is required.

The occurrence of sloshing forces may require close examination due to the relatively unbroken surface of the membrane and lack of internal bulkheads.

A variation of this system, which comprised one single layer of insulation with one Invar barrier, was adopted in 1968 on the 30 000 cu. metre *Ile de la Reunion* (ex *Hypolite Worms*) for the carriage of LPG until 1974.

The Gaz Transport System has been used on a number of ships for over a decade and has therefore accumulated a considerable experience. The successful record of this containment system has been emphasized by the performance on the *Polar Alaska* and *Arctic Tokyo*. Since the delivery of these

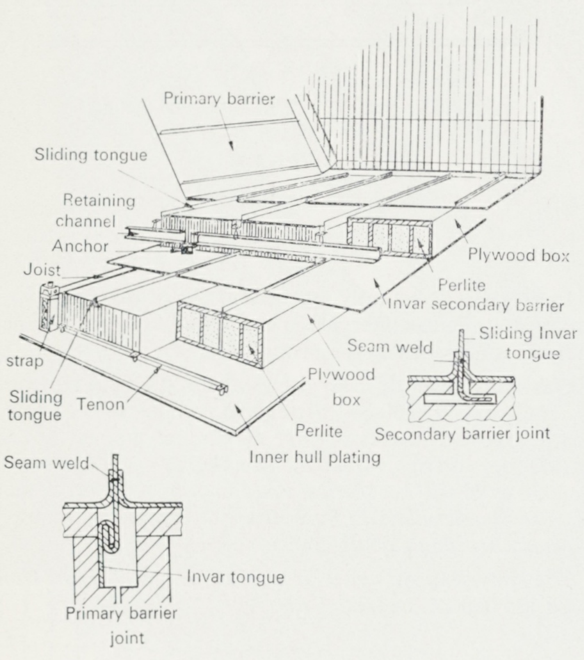


FIG. 8
Gaz Transport membrane system.

ships in 1969, they have been engaged in the rigorous weather service conditions prevailing between Yokohama and Alaska.

The LNG ships currently in service using the Gaz Transport Membrane System total 1 310 800 cu. metres in capacity. These include *Polar Alaska* and *Arctic Tokyo* 71 500 cu. metres, *Geomitra* and *Genota* 76 000 cu. metres, *Hassi R-Mel*, *Kenai Multina* and *Montana* 35 500 cu. metres, *El Paso Paul Kayser*, *Gastor*, *El Paso Sonatrach*, *El Paso Consolidated* and *Nestor*, 125 000 cu. metres, *Larbi Ben M'Hidi*, *Edouard L D* 129 500 cu. metres and *Methania* 131 000 cu. metres.

Ships now on order total 1 029 500 cu. metres

1.3 GAZ TRANSPORT/McDONNELL DOUGLAS MEMBRANE SYSTEM

In 1976, Gaz Transport and McDonnell Douglas Corporation introduced a membrane containment system for liquefied natural gas developed utilizing the knowledge and experience gained in their own particular fields.

This system utilizes the Gaz Transport INVAR membrane and the McDonnell Douglas 3D insulation system developed from their involvement in the Apollo/Saturn space programme for application to LNG ships (*see* Fig. 9).

The inner hull surface is shot blasted and coated with a layer of specially prepared non-porous polyurethane based primer and adhesive combination. This process permits bonding over normal surface irregularities such as weld beads and out of fair conditions. On top of this adhesive, one layer of secondary insulation is laid. This insulation consists of three dimensional orthogonal matrix of glass fibre yarn filled with polyurethane foam formed into blocks 3 metres long by 600 mm wide. The thickness of the blocks depends on the 'boil-off' rate required by the Owners, but it is in the order of 200 mm.

On the top of the secondary insulation blocks, a fatigue resistant glass fibre cloth liner impregnated with polyurethane adhesive is machine installed to form the secondary barrier. The adhesive is applied in measured amounts to all cloth faced edges of the 3D blocks which is then positioned to provide complete continuity of the secondary insulation structure. After a number of blocks have been positioned, a visual inspection is carried out to ensure that no significant voids are left in the adhesive between the blocks and beneath the edges of the secondary barrier. The joints are then covered with glass fibre splices to complete the secondary barrier surface. At this stage the adhesion of the secondary barrier is ensured by vacuum bag installation procedure. Once the secondary barrier liner is fully in position, a further layer of adhesive is laid over it and the primary blocks are placed. The primary blocks differ from the secondary ones in that no glass fibre cloth liner is fitted on the top surface of the former and a plywood channel is embedded at half width of each block. This channel serves as a retainer for the Invar tongue.

The primary barrier used in this system is composed of the well known Invar strakes used on the Gaz Transport Membrane System. These strakes are resistance welded to the Invar tongues which are fed through the tongue retaining channels. As in the case of the GT membrane system, the Invar strakes run the full length and width of the tank surface without butt joints and are arranged lengthwise against the top, bottom and sides of the tank and horizontally at transverse bulkheads. Each strake terminates on an Invar angle fitted round the perimeter of each transverse bulkhead and welded to it. The angle bar is secured to the inner hull by means of metallic couplers situated at intervals and positioned in the same direction as the tongues to transmit the load into the ship's structure. Leak detection in this system is achieved by periodical sampling of nitrogen gas that has been fed through the space between the Invar primary barrier and the primary insulation blocks and checked for the presence of methane. Thermocouples are installed on the glass fibre liner secondary barrier which would announce a drop in temperature in the secondary barrier resulting from a breach of the primary barrier.

It is worth noting that this system by virtue of its direct bonding to the inner hull is naturally influenced by the behaviour of the ship in a seaway and the resulting structural response. Due consideration must therefore be given to this aspect when designing this system.

A further development of the GT/MDC System is the adoption of plywood stand off panels. Rectangular panels 2 metres by 6 metres constructed in 14.8 mm thick exterior plywood are placed on epoxy adhesive mastic beads applied to the inner hull and spaced 127 mm apart parallel to the longer edge of the panels. They are secured to the hull by 13 mm diameter studs spaced evenly along the four edges of each panel. On pressing a levelling tool against the inner hull and compressing the epoxy beads, any surface undulations will

be accommodated. The panel-to-panel joints are sealed by means of plywood splice plates on either side of the support panels. Polyurethane adhesive is applied to the faying surfaces of the splices.

This method permits the 3D secondary insulation blocks to be factory bonded to the support panels.

This system is to be adopted on two 130 000 cu. metre LNG tankers to be built at Sun Shipbuilders in the USA.

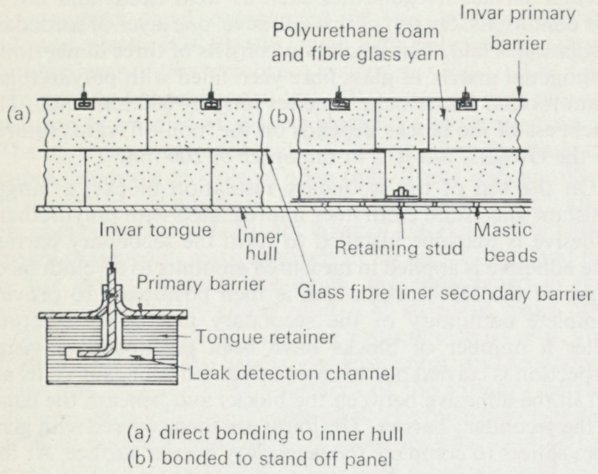


FIG. 9

Gaz Transport/McDonnell Douglas membrane system.

1.4 TECHNIGAZ MARK I MEMBRANE SYSTEM

In 1967, Conch International Methane Limited and Gaz Ocean S.A., joined to form a new Company called CONCH OCEAN LIMITED. The combined experience of the parent companies on cryogenic containment gave birth to the present Technigaz Membrane System, which utilizes the Technigaz stainless steel primary barrier as used on the *Pythagore*, and the Conch insulation and secondary barrier as used on the *Methane Princess* and *Methane Progress*.

The Technigaz membrane, *see* Fig. 10 conceived in the late 1950s by Øivind Lorentzen & Co. and Bo Bergtsson, Norway, consisted of a soft aluminium alloy 1100 to form a series of corrugations at right angles to each other. After extensive testing, Technigaz replaced this membrane by a 1 mm thickness of stainless steel and designed a containment system which consisted of identical stainless steel primary and secondary barriers, folded as described above, with PVC primary and secondary insulation. This system was installed on the ethylene and LNG carrier *Pythagore*.

After the formation of Conch Ocean in 1967, it was decided that a system, which would combine the proven Conch insulation and the Technigaz waffled stainless steel membrane, would be produced.

For the location of the Technigaz Membrane System, hardwood grounds are fastened at regular intervals to the inner hull plating to provide a level support. The spaces between the grounds, are filled with mineral wool. Panels, approximately 200 mm in thickness, are secured to these grounds. These panels are comprised of a laminate of balsa wood between a maple plywood layer as secondary barrier, and a douglas fir plywood layer as backing. The joints between these panels are sealed with PVC wedges with the surface of the panel sealed with a plywood scab piece. The primary insulation of balsa, secured to the plywood secondary barrier, provides the support for the now 1.2 mm stainless steel waffled primary barrier membrane. The waffles in the membrane are spaced approximately 300 mm apart with the shape of the corrugation having been slightly modified from the original design.

At corner sections, hardwood keys having the same thickness as the primary insulation are secured to the plywood secondary barrier in lieu of the balsa wood, and heavy stainless steel angles are located on top of these keys to provide an anchor for the membrane.

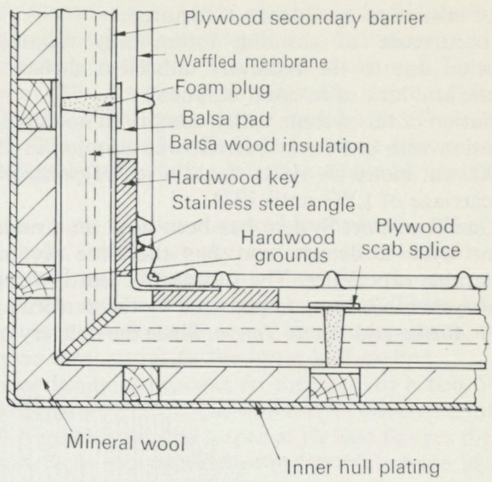


FIG. 10

Technigaz membrane system.

Inert gas is constantly fed behind the primary barrier and sampled at regular intervals to check for cargo contamination indicating a breach in the primary barrier.

Gas ships currently in service using the Technigaz membrane system, total 595 380 cu. metres and include *Shinryo Ethylene Maru* 1120 cu. metres, *Tellier* 40 000 cu. metres, *Descartes* 50 000 cu. metres, *Gadinia*, *Gadila*, *Gari*, *Gastrana* and *Gouldia* at 75 000 cu. metres, *Ben Franklin* 120 000 cu. metres, *El Paso Southern* and *El Paso Arzew* at 125 000 cu. metres and *Mostasa Ben Boulaid* 125 260 cu. metres.

The only ship on order at present is the *El Paso Howard Boyd* 125 000 cu. metres.

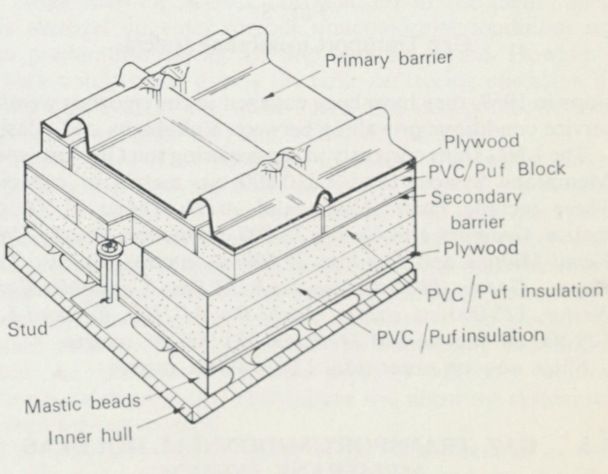


FIG. 11

Technigaz Mark II membrane system.

1.5 TECHNIGAZ MARK II AND III

This system is based on the concept devized for Conch Ocean utilizing the Technigaz stainless steel primary barrier with PUF or expanded PVC insulation materials in lieu of balsa wood, *see* Fig. 11. This design change is due to the economics involved with material availability.

The design concept is derived utilizing the load spectrum and arrangement of a 200 000 cu. metre ship. The system base is comprised of load bearing mastic beads, adhered to the inner hull, with a plywood facing to which standard panels 155 mm thick, formed by layers of PVC or PUF, are bonded. Additional fixation, for these preformed panels, is supplied by studs prewelded to the inner hull plating. The secondary barrier of plywood is fixed to the insulation panels, and 'scab splices' are located and bonded over the butting edges of the panels to ensure the tightness and integrity of the secondary barrier. Insulation pads 43 mm thick, faced with thick plywood, are attached to the secondary barrier with the plywood facing forming the support to the primary barrier. The primary barrier is constructed from 1.2 mm thick stainless steel to form standard corrugated sheets lap welded together.

Preformed corner sections are located on wood grounds with spaces, between grounds, filled with glass wool.

The Mark II system has been updated in the Mark III system to replace the plywood secondary barrier by a layer of 'Triplex' formed by a bonded laminate of aluminium and high strength glass fibre cloth.

Gas detection is accomplished by gas sampling utilizing the channels formed by the primary barrier corrugations.

The experience gained through the construction of the Mark I system for thirteen ships, and the development of the Mark III system have brought to light several areas where opportunities exist for improvement. A Mark I (MOD) containment system, still using sandwich panels with a balsa core, is at present being developed.

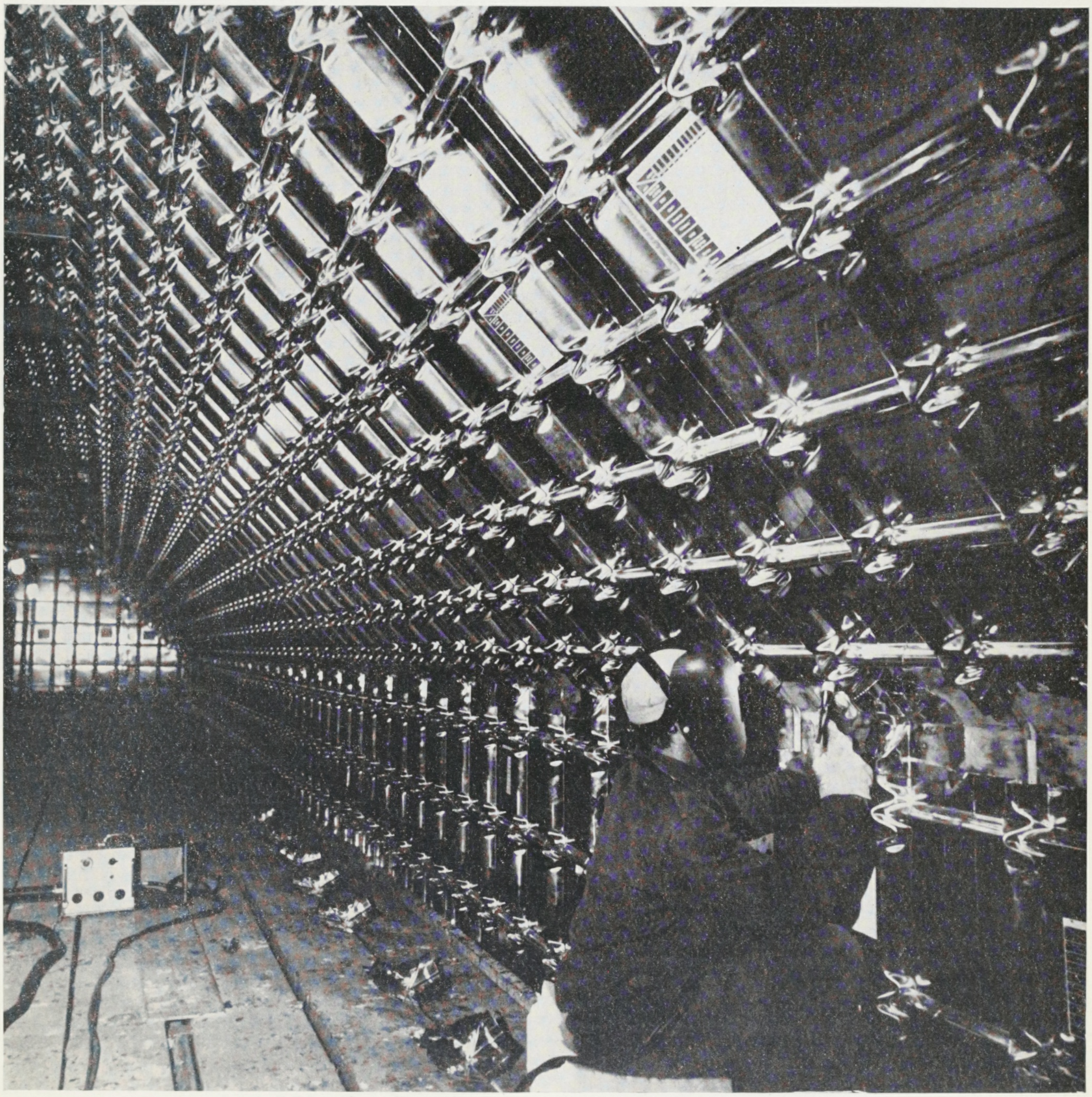


Plate VI. TIG welding of the stainless steel primary barrier of the Technigaz membrane system.

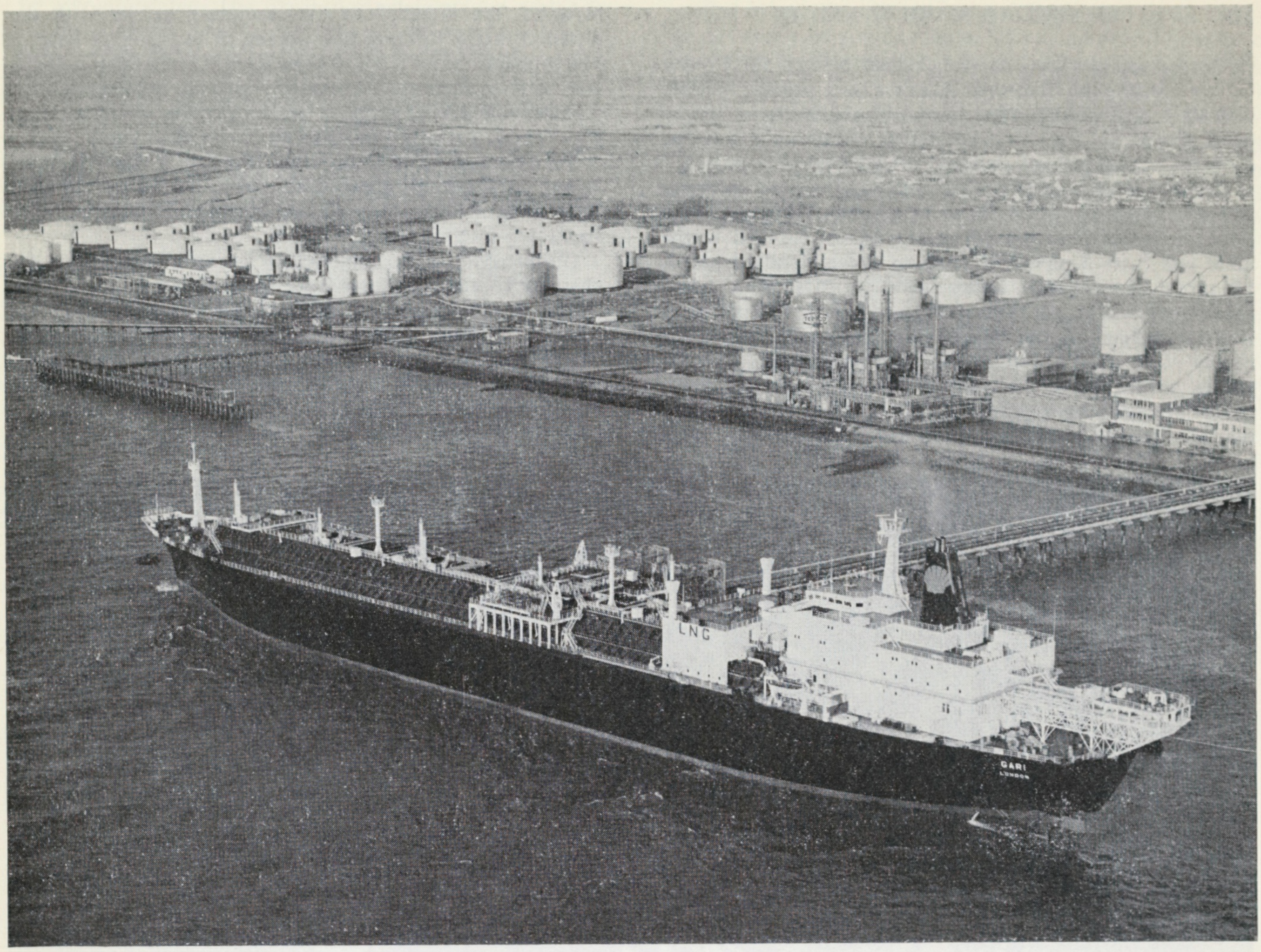


PLATE VII. The 75 000 cu. metre *Gari* fitted with the Technigaz membrane system, loading at the Canvey Island terminal.

1.6 TECHNIGAZ LPG MEMBRANE SYSTEM

This system has been designed by Technigaz for the carriage of LPG at a minimum temperature of $-55°C$ using an integrated tank design for double hulled ships where the inner hull, constructed of special quality steel, will serve as the secondary barrier.

This is a membrane system, *see* Fig. 12, using a laminate of impreganted glass fibre cloth, aluminium and impregnated glass fibre cloth (TRIPLEX) as the primary barrier bonded to a polyurethane foam insulation.

During the application, the inner hull surface is initially covered by a primer and glass fibre cloth suitable for the adhesion of polyurethane foam. Corner sections of preformed dense PUF are located by studs and bonded to the inner hull.

The polyurethane foam, 100 to 150 mm in thickness, is injected 'in situ' into portable moulds located by studs prewelded to the inner hull. After the removal of the moulds, the stud holes in the insulation are filled with PUF plugs bonded in place. The Triplex primary barrier is mounted in 1.3 metre widths and the joints in the Triplex covered by a 200 mm wide scab strip of the same material bonded in place. After verifying the joint integrity by vacuum testing, the primary barrier is coated with an elastomer based coating resistant to low temperatures which acts as an additional protection to the tight membrane.

A network of failure detection channels are formed within the PUF adjacent to the inner hull for the circulation and sampling of inert gas to verify the integrity of the primary barrier, as well as the integrity of the inner hull.

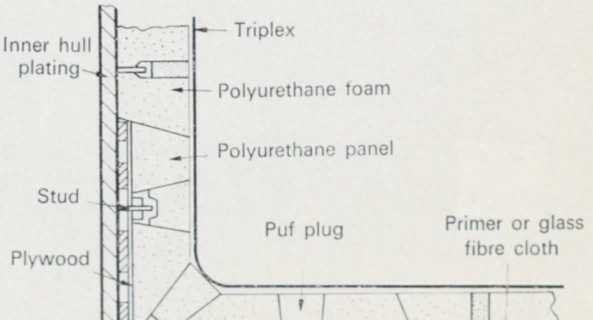


FIG. 12
Technigaz LPG membrane system.

APPENDIX II

SEMI-MEMBRANE CONTAINMENT SYSTEMS

2.1 BRIDGESTONE SEMI-MEMBRANE

The Bridgestone Liquefied Petroleum Gas Company, Tokyo, began the development of a semi-membrane system in 1960 for the containment of LNG in conventional double hull constructed ships, *see* Fig. 13.

The system membrane is designed to be constructed in a flat plate configuration, 4 to 8 mm thick, depending on tank size, in stainless steel, 9 per cent nickel steel or aluminium alloy. This membrane is independent and floats almost completely freely within the boundaries of the primary insulation, with restraint being applied at the tank dome position. The stainless steel secondary barrier is embedded within two or more layers of coated plywood supported by a wooden frame attached to the inner hull. This frame is filled with polyurethane foam with fibrous glass, or mineral wool to provide the secondary insulation.

The insulation space is kept permanently inerted. Gas is fed, for sampling purposes, behind the primary membrane and thermal sensing devices are positioned on the inner hull.

This system has been fitted to two ethylene carriers, *Ethylene Dayspring*, 1100 cu. metres, and *Ethylene Daystar*, 890 cu. metres, the LPG carrier *Bridgestone Maru V*, 72 350 cu. metres, and seven LPG tankers totalling 546 180 cu. metres.

Sasebo-Heavy Industries have further developed this design with the substitution of a stainless steel drip tray for the complete secondary barrier coming into direct contact with the tank. The load bearing insulation consists of two layers within a lattice structure of plywood joists. The outer insulating layer constructed from polyurethane foam within the inner layer from phenolic foam.

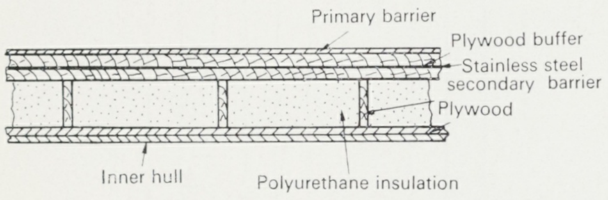


FIG. 13
Bridgestone semi-membrane system.

2.2 IHI FLAT TANK SYSTEM

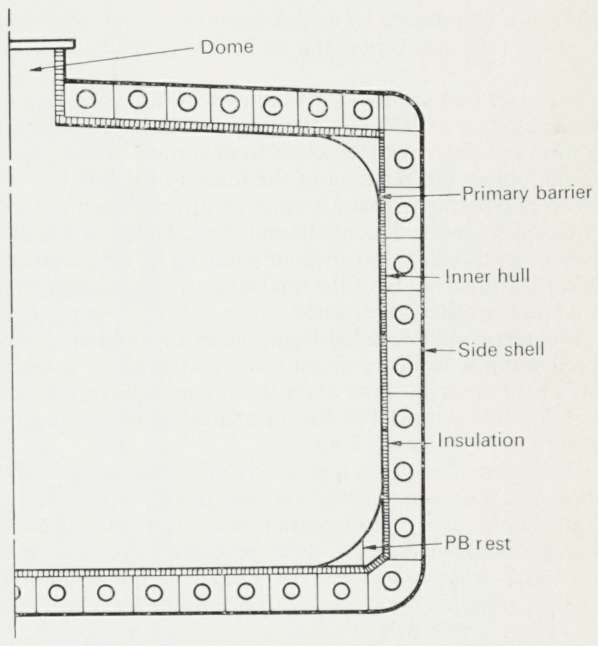
In 1958 Ishikawajima-Harima Heavy Industries Co. Ltd., began their involvement in liquefied gas ships. Since that date, they have built 13 gas ships and a number of land-based installations for the storage of liquefied gas. In 1968, IHI utilized their established technical experience to devise a semi-membrane containment for the carriage of LNG at −162°C.

The tanks have been designed on the basis of 'leak before failure' utilizing extensive analysis and, as such, only require a partial secondary barrier. They are designated type B tanks.

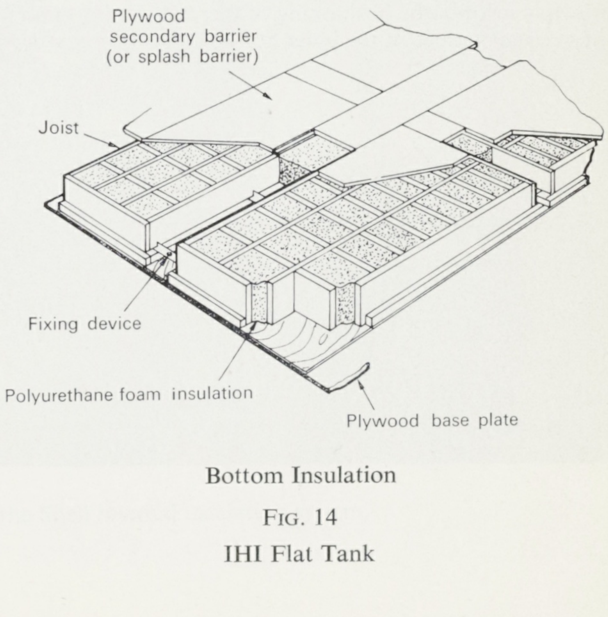
The 'Flat Tank' is a rectangular structure, fitted with a dome, constructed in aluminium alloy 5083–0, 15 to 35 mm in thickness, consisting of six plane surfaces with specially faired curved edges and corners, *see* Fig. 14. The thickness of the tank plating, more substantial than normal membrane configuration, allows the structure to be self-supporting during construction and, when empty, in service. The faired curved edges and corners are designed to absorb the contraction of the tank, at low temperatures, and the plating deformations due to fluid pressure.

The tanks are supported by the insulation covering the inner bottom of the ships double hull configuration. A network of plywood/insulation units is attached to the inner hull. A secondary lattice of plywood partitions is located within the unit and filled with plastic foam. A 25 mm plywood secondary barrier covers the insulation network in the lower part of the hold to provide for the temporary retention of LNG in the event of small leakages. The side wall and top insulation above this area is designed to be splash tight. A gas detection system is incorporated in the space between the inner hull and cargo tank to test for primary barrier leakage.

The rounded corners of the tank are supported at the bottom by shaped chocks to prevent excessive sagging of the tank sides. Anchoring devices to restrain transverse and longitudinal movement of the flat tank are situated at the dome and bottom plating.



Typical Section



Bottom Insulation

FIG. 14
IHI Flat Tank

APPENDIX III

INTERNAL INSULATION CONTAINMENT SYSTEMS

3.1 SHELL INTERNAL INSULATION SYSTEM

In 1965, Shell International Marine contracted Shell Research Limited, at Thornton to produce a viable and economic containment system suitable for the carriage of LPG.

A system was evolved based on polyurethane foam as the insulating material and culminated in large scale tests being performed in 1969 with the fitting of special tanks to the tanker *Aulica*. The tanks were summarily removed in 1970 after 18 months' service for laboratory inspection and further testing.

This internal insulation system, *see* Fig. 15, involves a 100 mm layer of polyurethane foam for insulation and cargo containment. The foam surface is exposed to the liquefied gas cargo and relies on a temperature gradient across the insulation to the inner hull, that acts as the secondary barrier. This gradient is maintained by a back pressure on the liquefied gas caused by the gas vaporizing as it permeates the insulating material.

The inner hull, constructed of low temperature steel suitable for the carriage of LPG at −50°C, is shot blasted and inspected by infra red lamps for the detection of surface conditions that will not allow full bonding of the foam to the hull.

The polyurethane foam is sprayed directly onto the inner hull in layers approximately 10 mm thick. The thickness of the layer depends on the position of spraying in the cargo tank. Before the application of the final layer, a hessian skin, acting as a crack arrester, is attached.

The corner and bevelled locations in the hold are initially faired using a wood or foam coving to produce a smooth surface for the application of the insulation. A further development in this region will be the installation of complete corner sections in high density foam.

The system depends to a great extent on the proven characteristics of the foam material and the application of the foam layers requires the implementation of stringent quality control procedures to ensure that these properties are maintained. After each layer is applied, the surface of the insulation is sounded using acoustic means to determine the existence of any debonding or delamination.

The fundamental philosophy behind this system is the definition of the complete depth of the foam insulation as the primary barrier, and, hence, the existence of any breach in the primary barrier relies on detection at the inner hull. This principle justifies the positioning of thermal sensing cables on the external surface of the inner hull to detect primary barrier failure with the deviation from the minimum design temperature.

The Society has approved this system without the hessian crack arrester as data gathered from operational experience has shown that this component may provide in-built defects which promote fatigue cracks in the foam.

This system has been fitted to the 77 000 cu. metre LPG ships *Pioneer Louise* and *Gas Gemini*, and the 76 000 cu. metre *Gas Diana*.

This concept is, at present, being further developed for the containment of LNG cargoes.

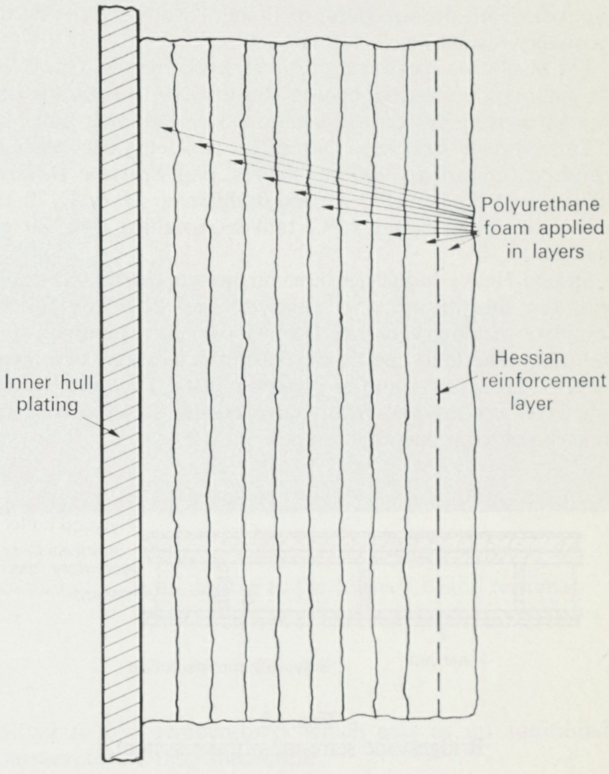


FIG. 15
Shell internal insulation system.

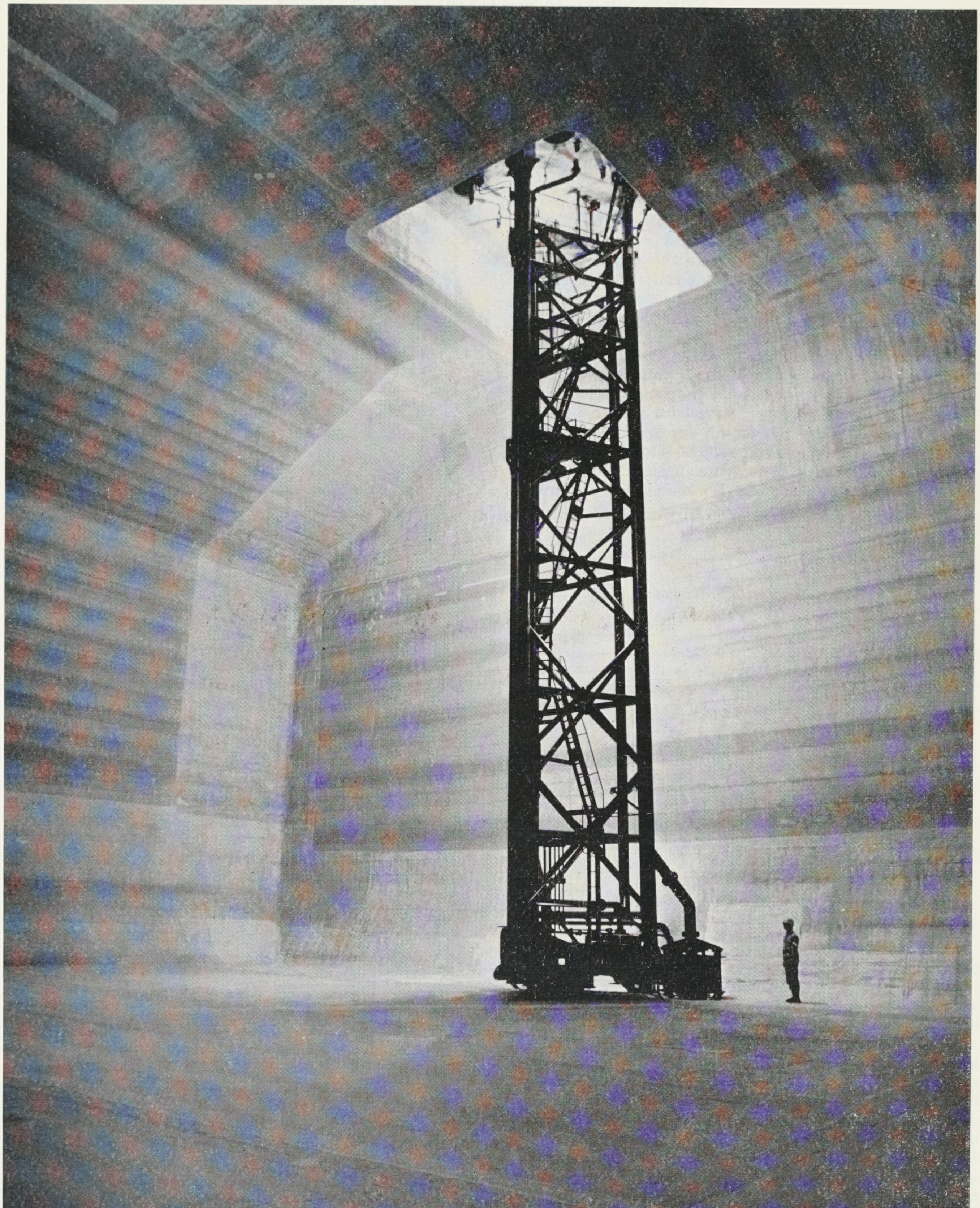


Plate VIII. An LPG cargo tank fitted with the Shell internal insulation system.

APPENDIX IV

INDEPENDENT TANK CONTAINMENT SYSTEMS

4.1 CBI SPHERICAL CONTAINMENT SYSTEM

The Chicago Bridge and Iron Company have developed this spherical containment system from their experience gained in the design of land-based storage vessels for liquefied gases under pressure. This design is similar in concept to the other spheres on the market, with the difference lying in the support arrangement.

The cargo tanks are independent type B spheres constructed in 9 per cent nickel steel or aluminium alloy. The sphere is supported on a large number of vertical colunms connected to the tank shell by large flat plate brackets slightly below the equator. These columns are allowed to rotate about their base in the transition of cooling the tanks during loading. The tanks are keyed horizontally at the equator against pitching and rolling motions.

The vertical column supports, *see* Fig. 16, are insulated at their base by Permali blocks. The tank insulation comprises polyurethane foam sprayed onto the inner hull structure and weather cover. A drip tray is provided beneath the sphere as a partial secondary barrier with any small leakages being passed to the drip tray by spray shields situated at the side.

This spherical containment system has been employed on the experimental Esso ship *Sankyo Ethylene Maru* since 1974 and is now fully operational in the carriage of ethylene.

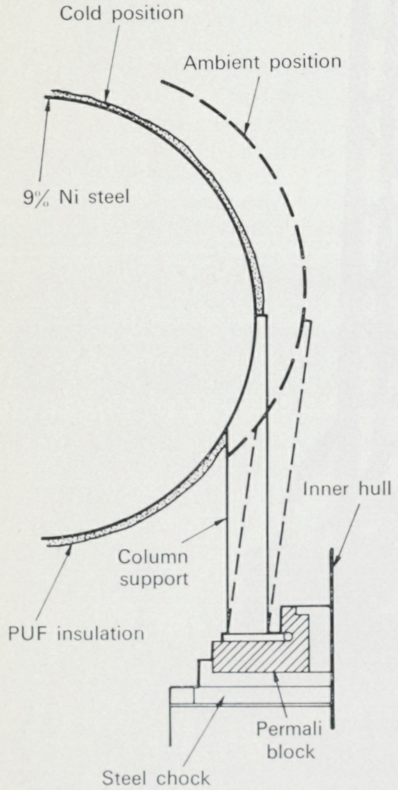


FIG. 16

CBI Independent tank support arrangement

An alternate design has been developed in conjunction with Hitachi Zosen. In this arrangement, Fig. 17, the support to the sphere is provided by a 'Gear Support System'. This consists of two horizontal ring girders, located just below the tank equator, and joined together by vertical stiffeners. A series of keys are attached to the lower ring girder in line with the vertical stiffening. These keys engage with keyways mounted on the support deck of the ship's hull. This configuration restricts circumferential and vertical movement whilst allowing for radial displacement of the tank during cooling down.

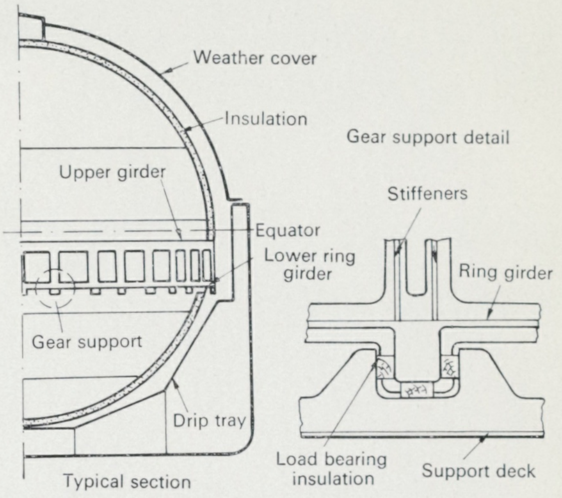


FIG. 17

Hitachi Zosen/CBI independent tank system.

4.2 CONCH FREE STANDING LNG TANK

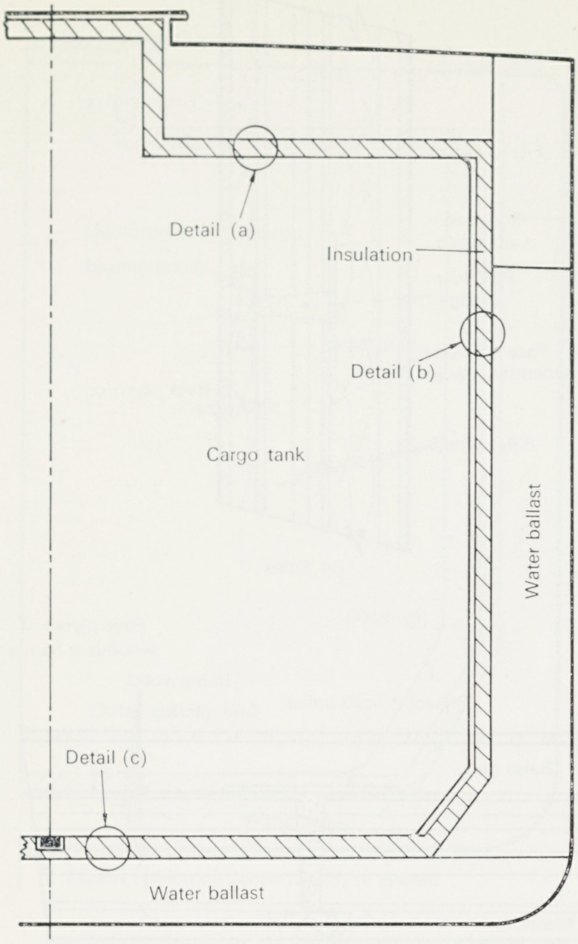
The development of the present day CONCH free standing LNG tank known as the CONCH 2 system has been evolved in a series of design stages originating from the early feasibility project set up by Constock Liquid Methane Corporation and the North Thames Gas Board. This project involved the conversion of the dry cargo ship *Normarti* to the 5000 cu. metre LNG carrier *Methane Pioneer* to carry the first LNG cargo from Louisiana to Canvey Island in 1959. The system was modified for the *Methane Progress* and *Methane Princess* in 1964, before undergoing the last design changes incorporated in the new version, CONCH 2 system.

The *Methane Pioneer* was fitted with rectangular tanks constructed in 5356 aluminium, *see* Fig. 18. The tanks were horizontally stiffened with diagonal angle corner ties and horizontal ties connecting the sides of the tank. The tanks were supported on load bearing insulation distributed over the inner bottom structure.

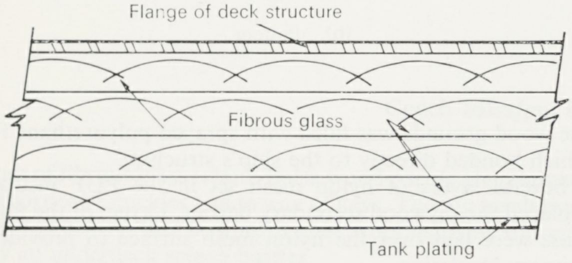
The bottom insulation consisted of mastic set balsa laminates forming panels of approximately 400 mm in thickness. The panel was faced on the inner side with Sugar Maple plywood and on the back with Douglas fir plywood. PVC foam wedges were used at the panel joints. The face plywood acted as the secondary barrier and was sealed at the panel joints with plywood extension joints. The primary insulation consisted of a thin balsa pad. Before the application of the bottom insulation, the inner bottom surface was fitted with a 12 mm thickness of soft balsa wood to provide a uniform support for the tank through local crushing.

The side insulation was similar to the bottom insulation, but the thickness was only 300 mm and a void space was left between the tank plating and the plywood secondary barrier.

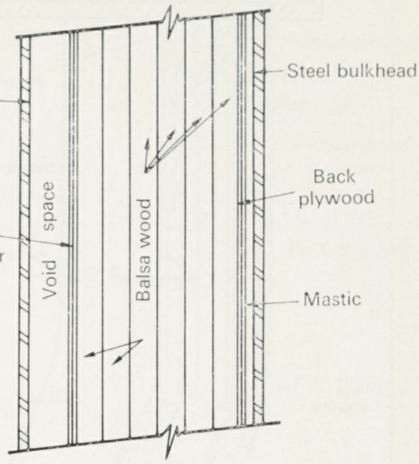
The top insulation consisted of multiple layers of fibrous glass wool between the top of the tank and the underside of the deck transverse web flanges.



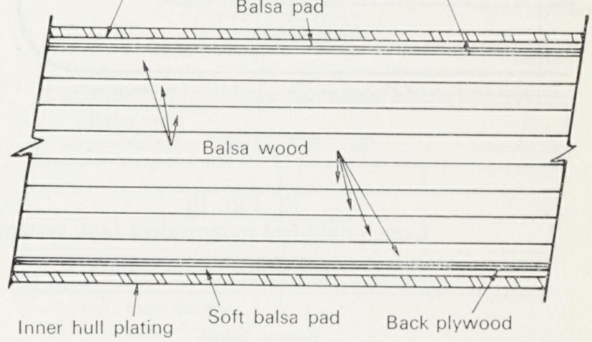
Typical section of Conch original system (Methane Pioneer)



(a) Top



(b) Sides



(c) Bottom

Fig. 18
Conch original independent tank system.

Aluminium keys were fitted at the bottom centreline of each tank and corresponding keyways were incorporated into the centreline bottom insulation panels. The material in way of the keyways was hardwood. Keys for restraining motion during rolling and pitching were fitted to the underdeck structure with the female half fitted to the top of the cargo tank.

The experience gained from the experimental *Methane Pioneer* led to the insulation system being substantially modified although the basic concept was essentially retained. The modified version, *see* Fig. 19, was, in 1964, fitted on the first commercial LNG ships, the 27 400 cu. metre *Methane Progress* and *Methane Princess*, which were placed in service between Arzew in Algeria and the U.K.

The tank material was changed to 5083 aluminium alloy and a centreline bulkhead was introduced. The arrangement of the top keys was also altered slightly with the male part fitted to the top of the cargo tank. Four roll keys and two pitch keys were installed on each tank.

The insulation on the tank bottom now consisted of balsa plywood sandwich panels, 190 mm in depth, set upon wood grounds approximately 40 mm thick to provide level support. The spaces between the grounds were filled with a load bearing mastic. The reduction in the thickness of the panel was compensated by increasing the thickness of the balsa pad located on top of the secondary barrier face plywood to 75 mm.

The back plywood of the side insulation was set on 50 mm wood grounds and the spaces between the grounds were filled with fibrous glass wool. The secondary insulation panel thickness was reduced to slightly less than 120 mm. On the secondary barrier face a 75 mm layer of fibrous glass was laid. This left a small space between the primary barrier and the fibrous glass surface which allowed enough clearance for lowering the tank into the hold space. The top fibrous glass insulation was essentially retained as on the original version.

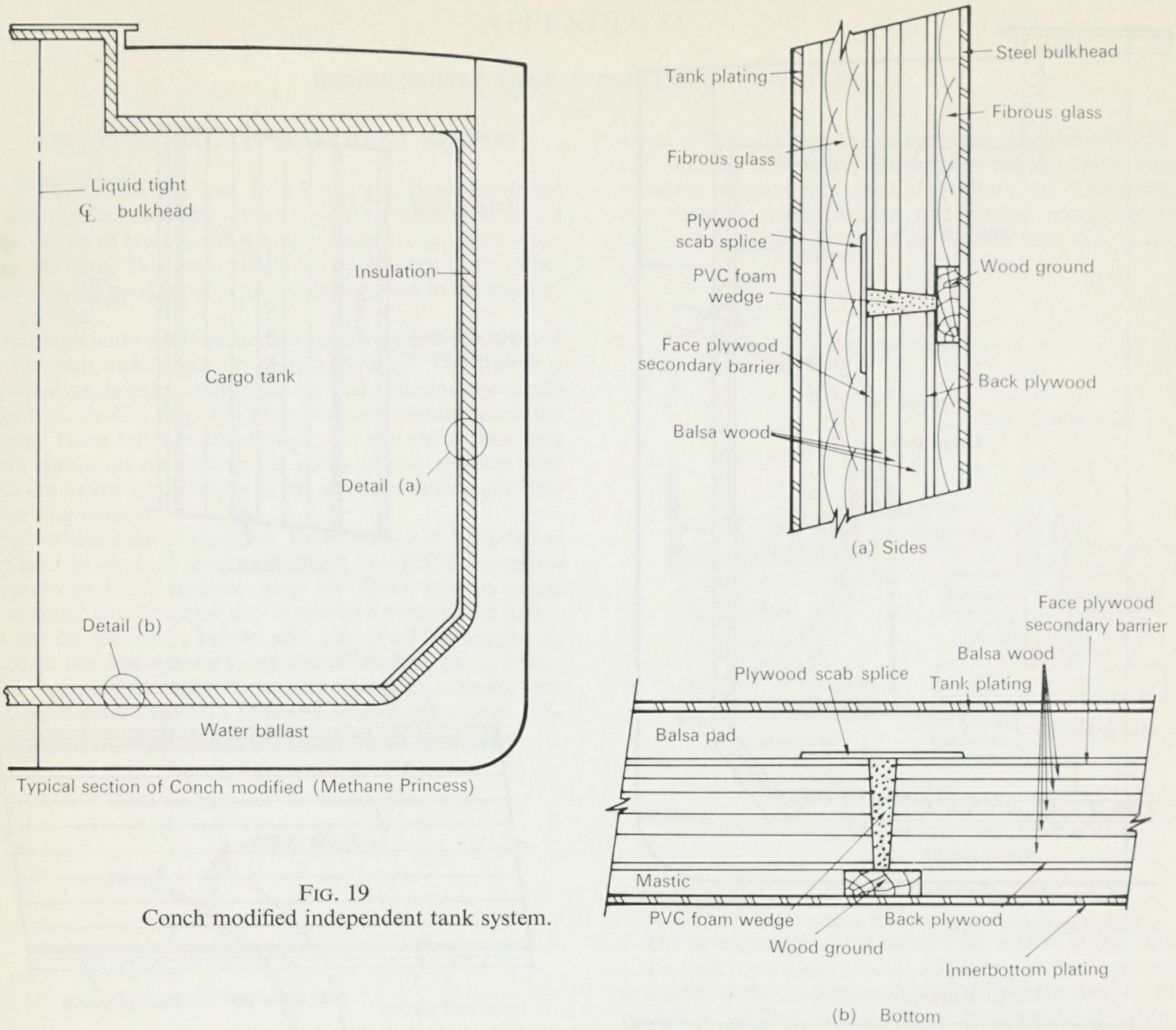


FIG. 19
Conch modified independent tank system.

CONCH BALSA/PUF CONTAINMENT SYSTEM

The system adopted on the *Methane Princess* and *Methane Progress* allowed a very small space between the primary barrier and the surface of the fibrous glass insulation for the lowering of the tank into position after the bottom and side insulation had been installed. It was later argued that whilst this was perfectly feasible when dealing with small tanks, it might become a problem where large heavy tanks were involved. This would necessitate building the tanks in situ and therefore a lot more space between the tank and the insulation had to be provided (this design philosophy was later revised with improved technology and better lifting equipment enabling the tanks to be built away from the ship's hold and transported bodily to the building site with the insulation already in position). This interim design involved various modifications to the existing insulation construction, *see* Fig. 20.

The upper part of the side insulation above the hopper tank top knuckle was changed from balsa panels to a wooden framework enclosing fibrous glass with a plywood splash barrier cover forming the secondary barrier. The bottom, lower sides and top insulation remained as before.

A further development in the side insulation was the substitution of reinforced polyurethane foam for the fibrous glass to the depth of the tapered edge balsa panels located on wood grounds at corners and upper boundaries. The space between the wood grounds was filled with sprayed polyurethane foam which bonded directly to the ship's structure.

Several layers of nylon mesh set in the PUF insulation replaced the plywood secondary barrier. Layers of the fibrous glass were laid over the nylon mesh surface to provide the primary insulation.

CONCH 2 CONTAINMENT SYSTEM

This is the latest Conch system developed under licence by Sumitomo Heavy Industries of Japan, *see* Fig. 21, and adopts the same principle as the previous systems. The tank is supported on balsa island panels, tapered at the edges, located on the inner bottom plating.

Polyurethane foam is sprayed directly onto the tank top to a depth of approximately 150 mm to fill the spaces between the island supports. The foam adheres to the ship's structure and the tapered edges of the supports. A 0.35 mm glass fibre mesh net is glued to the surface of the PUF. This is considered to provide a means of crack arresting in the foam surface. Layers of fibrous glass to a thickness of about 150 mm fill the remaining space between the foam surface and the bottom of the containment tank. The total thickness of the bottom insulation is approximately 300 mm.

Similarly, the side insulation consists of 150 mm of polyurethane foam covered with the glass fibre net, onto which

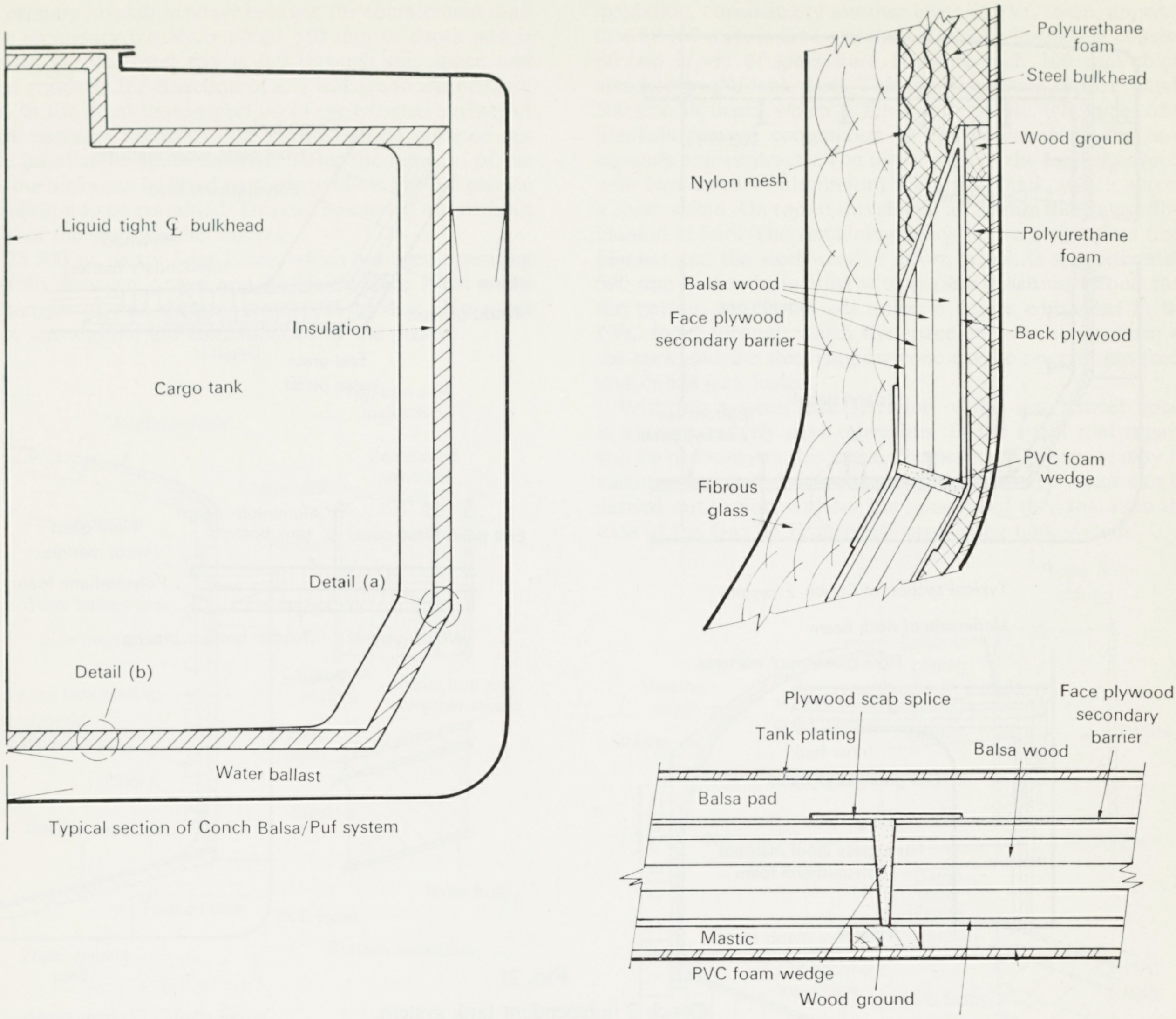


FIG. 20

Conch balsa/puf independent tank system.

150 mm of fibrous glass is laid. Balsa wood panels are retained at the corners, knuckles and in way of keys. The top insulation remains as before, that is, fibrous glass wool mattress supported by an underdeck splash barrier.

The space left between the primary insulation and the primary barrier at side is between 500 and 560 mm. This void space is inerted with nitrogen gas and provides convenient routing for gas sampling and leakage alarms. It could also be used for inspection should tank integrity become suspect.

The CONCH 2 system is to be installed on three ships totalling 375 000 cu. metres now building at the Avondale Shipyard in the USA.

The tanks are supported on chocks constructed of balsa blocks on 9 per cent nickel steel bearers.

The insulation is applied directly to the outer tank plating and consists of two layers of polyurethane foam panels with an intermediary layer of plywood. A sheathing of aluminium is positioned on the outside surface of the insulation.

The intermediary space between the inner and outer tank plating is filled with inert gas which is utilized to detect cargo tank leakage.

This design is incorporated in four ships plying trade between Libya and Italy and Spain, the 41 000 cu. metre methane carriers *Esso Brega*, *Esso Porto Venere*, *Esso Liguria* and the 40 000 cu. metre *Laieta*.

4.3 ESSO SELF-SUPPORTING ALUMINIUM CONTAINMENT SYSTEM

This system was designed by ESSO in 1966 for the carriage of LNG.

The design consists of self-supporting prismatic tanks, *see* Fig. 22, constructed utilizing a double envelope system in aluminium alloy. The inner envelope plating forms the primary barrier and is connected by T-section webs to the outer envelope plating which forms the secondary barrier.

4.4 GAZ DE FRANCE SELF-SUPPORTING CYLINDRICAL TANK

Gaz Transport, as Gaz de France, a member of the Worms & Cie. Group, entered into an association with certain French Shipyards to evalaute three different self-supporting tank designs. This experimental work was undertaken by the Methane Transport Company, formed by the above concerns, using the converted Liberty ship *Beauvais*. After an extensive testing period, a vertical cylindrical design, proposed by

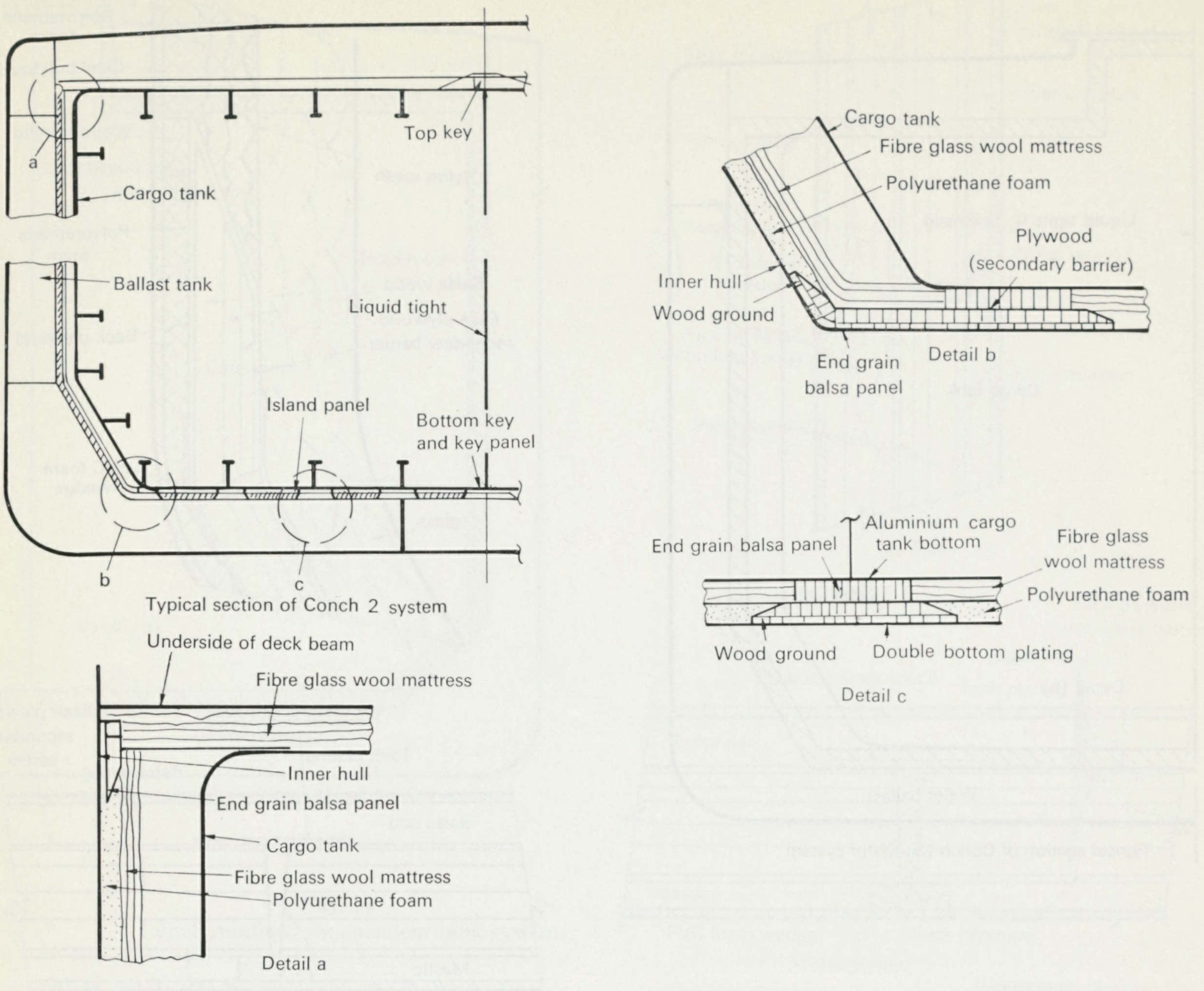


FIG. 21

Conch 2 independent tank system.

Ateliers et Chantiers de la Seine Maritime and Forges et Chantiers de la Mediterrannee, was adopted.

This containment system, *see* Fig. 23, employs vertical cylindrical tanks constructed in 9 per cent nickel steel. The tanks are stiffened internally by six horizontal rings of a rectangular box section. The top and bottom rings, which are in line with the two rows of tank keys, are further reinforced with horizontal flat plate webs, two anti-roll and two anti-pitch keys, fitted at each ring. These keys retain the tank when under contraction during cargo loading and also provide lifting points. The tank top is ellipsoidal in section and extends above the upper deck of the ship. Steel covers protect the top of the tanks. The bottom of the tank is constructed as an inverted cone spherically shaped at its apex. The inner bottom of the ship's hold has the same slope as the tank bottom.

The bottom insulation consists of layers of load bearing PVC foam approximately 450 mm in final thickness upon which is placed a 9 per cent nickel steel tray, acting as the secondary barrier. A further thin layer of PVC provides the primary insulation separating the tank plating from the secondary barrier. The top and sides of the insulation system consist of a layer of PVC foam, approximately 65 mm thick, attached to the inner surface of the weather shield and the inner hull plating extending down to the steel tray at the bottom. A fabric reinforced polyester film is then bonded to this layer forming the secondary barrier. In way of the keys, the secondary barrier consists of a stainless steel sheet to which the reinforced polyester film is also bonded.

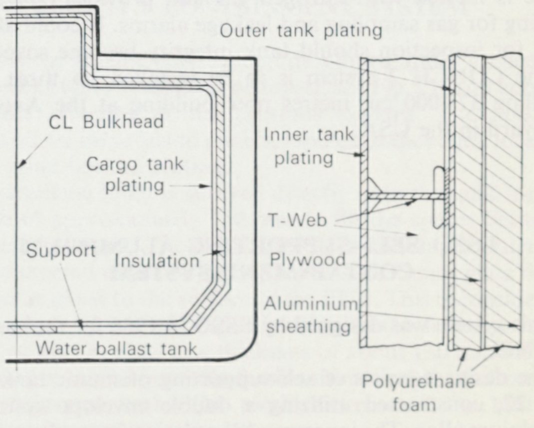


FIG. 22

Esso independent tank system.

The primary insulation space between the containment tank and the secondary barrier is about 550 mm in depth and is filled with perlite. Inert gas is fed through this space and sampled regularly for detection of any leakage in the primary barrier. In the event that inspection of the external surface of the tank becomes necessary, the perlite can be pumped out and the interbarrier space entered. After the removal of the perlite, the tanks can be lifted partially to allow bottom plating and insulation to be examined. This can be carried out without removal of the steel weather covers.

The 25 500 cu. metre *Jules Verne*, which has been operating successfully between Arzew and Le Havre since 1965, is the only example of this design constructed to date. No more ships, to this design, are contemplated at the present.

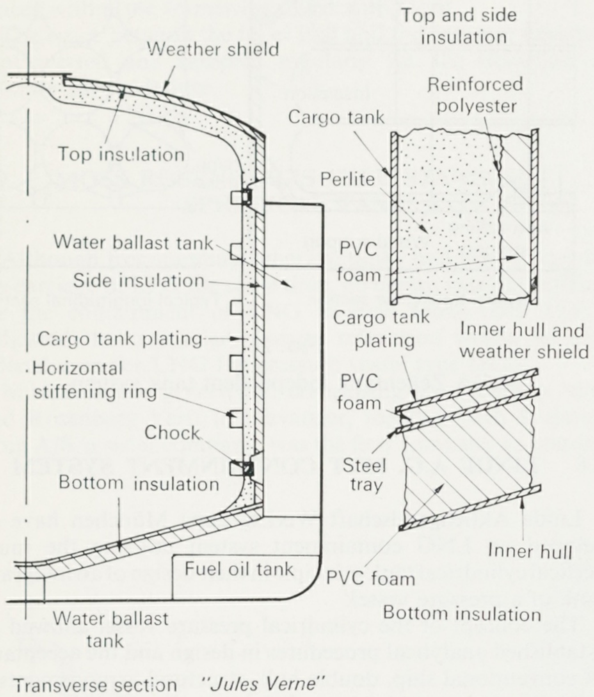


FIG. 23

Gaz de France independent tank system.

4.5 GAZ TRANSPORT/PITTSBURGH DES MOINES (GT/PDM) FREE STANDING SYSTEM

In 1972, Pittsburgh des Moines, a steel construction company, of Iowa, USA, entered into an agreement with Gaz Transport, Paris, to combine their respective experience and develop a containment system for the transportation of liquid natural gas by sea. This system could be considered as a further development of the Gaz de France self-supporting tank.

The tank, *see* Fig. 24, is constructed in lightweight aluminium alloy in four geometrical shapes. The top of the tank is hemispherical, the centre portion cylindrical and the bottom conical with a spherical apex. These tanks are similar in concept to spherical designs and entirely unstiffened. They project above the level of the deck and are protected by steel weather covers.

Anchoring arrangement is by means of holding down tension straps placed at intervals on the circumference at the lower knuckle.

The bottom insulation consists of two layers of PVC foam, each approximately 100 mm thick, placed on the conical support base. On top of these layers an aluminium alloy drip tray forming a partial secondary barrier is placed. The primary insulation, consisting of another layer of PVC foam, approximately 100 mm, is then attached. The side insulation consists of two layers of glass fibre blankets each 100 mm thick, attached to the tank shell. This leaves a space approximately 500 mm in depth which is filled with perlite. The glass fibre blankets prevent compaction of the perlite when the tank expands and contracts. The upper part of the tank is covered with two layers of aluminium foil 1 mm thick, which acts as a spray shield. On top of this shield, an 80 mm thick glass fibre blanket is laid. The remaining space between the glass fibre blanket and the steel weather cover, which is approximately 500 mm in depth, is filled with perlite. It is understood that the bottom insulation will utilize a device embedded in the PVC foam through which the space between the bottom of the tank and the steel support cone can be purged, gas freed and halide leak tested.

With this system, leak detection of the interbarrier space is a comparatively easy operation. In the event that repairs will be necessary in this space, the perlite in the space may be vacuum removed. It is understood that damage repair can be carried out in port without the removal of the tank as in the case of the Gaz de France self-supporting tank system.

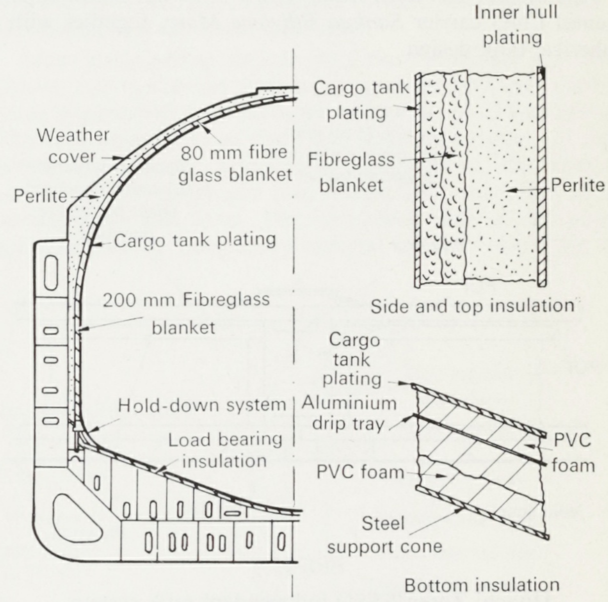


FIG. 24

Gaz Transport/Pittsburgh des Moines independent tank system.

4.6 HITACHI ZOSEN/ESSO LNG SYSTEM

Hitachi Zosen began development of their free standing LNG system, in 1963, with the first concept presented in 1969 based on their technology gained in the construction of LPG carriers.

This initial design was furthered when, in 1970, they entered into a contract with ESSO International Inc. for a joint research and development program to evolve a 125 000 cu. metre LNG carrier design utilizing the Hitachi Zosen LNG containment system.

The cargo tanks are independent, self-supporting, prismatic type tanks constructed in 9 per cent nickel steel. The tanks are stiffened longitudinally at top and bottom, and vertically at sides and ends. The primary structural members are formed by transverse webs at top and bottom together with a horizontal ring system of continuous stringers at sides and end bulkheads.

The cargo tanks are supported on phenol resin laminate

chocks located on the inner bottom plating in line with plate-floors. Chocks, to prevent the movement of the tank, are situated on the top and bottom of the tank; at the centreline, to prevent transverse motion, and, at the midhold position, to prevent fore and aft translation. Anti-flotation chocks are provided at the top of the tank at side.

The insulation, *see* Fig. 25, is applied to both the cargo tank and the inner hull of the ship. The external surface of the tank is subdivided by wooden and high density foam spacers. An initial layer of low density foam is foamed in situ between the network of spacers and followed by a layer of high density foam. The outer surface of the primary insulation is covered by a GRP sheet for protection against humidity and mechanical damage. Plywood boxes filled with polyurethane foam are located on the anchor pieces leaving a void space at the inner hull surface for drainage. The secondary barrier, consisting of a plywood layer bonded between two aluminium sheets, is attached to the inner surface of the secondary insulation.

The space between the primary and secondary insulation is kept fully inerted with nitrogen gas to monitor the primary barrier integrity. The secondary barrier is monitored via the drainage channels at the inner hull.

This system has been fitted to the 1100 cu. metre experimental LNG carrier *Sankyo Ethylene Maru*, together with a spherical tank design.

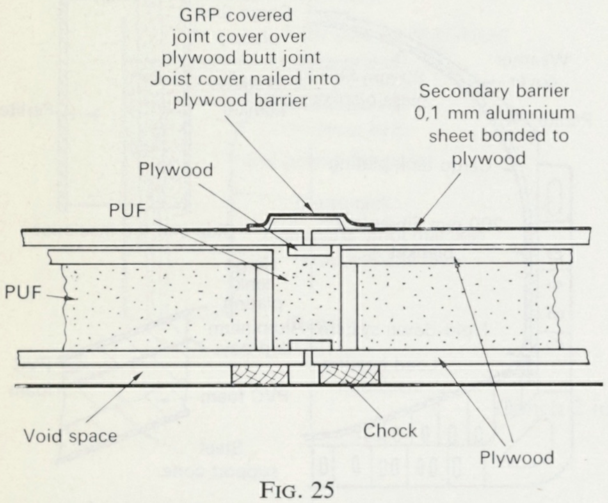


FIG. 25

Hitachi Zosen/ESSO independent tank system.

4.7 LGA ZELLENTANK SYSTEM

In 1972, Liquid Gas Anlagen Union GmbH, introduced a system employing horizontally stacked cylinders, designated independent tank type C, for the containment of methane at −160°C.

This system is based on the experience gained with their previous multi-lobed horizontal cylindrical system constructed in aluminium alloy that has been fitted to five small LNG carriers, *Anna Schulte*, *Sophie Schulte*, *Lissy Schulte*, *Heriot* and *Melrose*.

The cylinders, *see* Fig. 26, are constructed in aluminium alloy 5083–0 and located in stacks by double plane trusses which convey the resultant loads to the hull structure by friction type wood chocks. The cylinder stack is inter-connected vertically by connecting collars in the centre of each tier with the lowermost layer connected horizontally. A 32 000 cu. metre gas ship employing this design would incorporate 32 cylinders per hold, stacked four deep, in four holds.

Insulation, in the form of prefabricated polystyrene panels, is applied to the inner hull and double bottom of the ship. The panels are comprised of three layers of polystyrene, for the inner hull at side, and four layers for the double bottom. A layer of mineral wool covered by a fibre glass reinforced plastic is applied to the inner hull insulation and a 2.5 mm aluminium sheath applied to the double bottom insulation.

A slight overpressure of nitrogen is maintained in the spaces between cargo tanks and hold insulation. Gas detection is accomplished using the gas sampling of nitrogen gas.

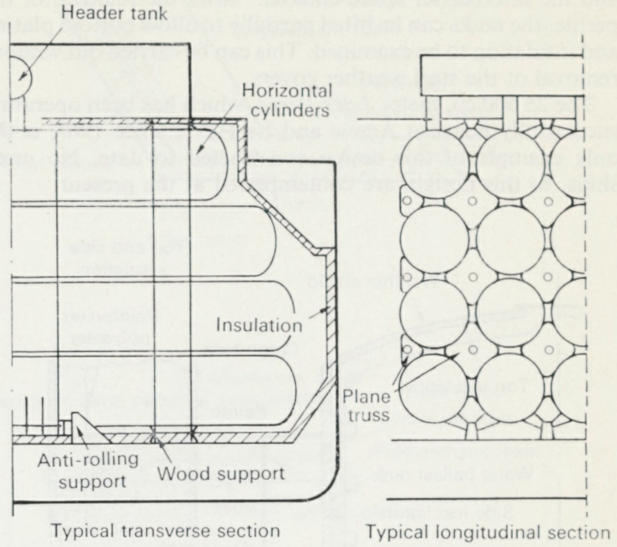


FIG. 26

LGA Zellentank independent tank system.

4.8 LINDE A.G. MVT CONTAINMENT SYSTEM

Linde Aktiengeselschaft Werksgruppe München have developed an LNG containment system utilizing the multi-vertical cylindrical tank principle in their design of an integrated tank of a pressure vessel.

The concept of the cylindrical pressure vessel allowed for established analytical procedures in design and the acceptance of conventional ship, double hull, structural arrangements.

Linde propose an integrated tank, *see* Fig. 27, composed of up to 50 vertical cylindrical vessels, approximately 2.5 metres

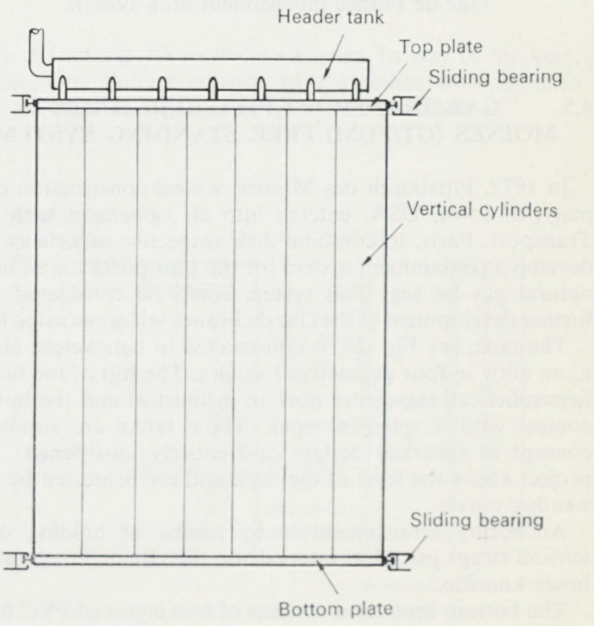


FIG. 27

Integrated tank of Linde independent tank system.

in diameter, constructed in aluminium alloy attached to horizontal plates at top and bottom. The upper plate supports a horizontal cylindrical header tank and the associated interconnecting piping. There is no piping at the bottom of the tank. Inspection is facilitated by the inclusion of manholes at the top of each vertical cylinder. A 125 000 cu. metre gas carrier would require 694 cylinders connected to 16 header tanks to form 16 integrated tanks.

The integrated tank rests on the bottom insulation of wood. The horizontal and vertical motions of the tank are absorbed and transmitted to the hull structure by sliding bearings at the corners of the top and bottom plates locating the cylinders.

The inner hull, top and sides, are insulated by foam panels adhered to the inner surface of the plating. A framework of plywood or balsa is attached to the inner bottom with the spaces within the framework filled with foam.

The space between the inner hull and the pressure vessels is kept inerted and sampled regularly for the detection of primary barrier failure.

4.9 MOSS ROSENBERG'S FREE STANDING SPHERICAL TANK

Although free standing spherical tanks had been in use for the carriage of LPG for some time, no design was put forward for the containment of LNG in such tanks until USCG indicated that secondary barrier relaxation would be considered even for LNG for pressure vessel type tanks.

Moss Rosenberg Verft a.s., comprising Moss Verft in Moss and Rosenberg Verft in Stavanger, together with Kvaerner Brug A/S, a sister company, was the first company to respond to this for large scale, commercial ships, and on the basis that a spherical tank could be considered as a pressure vessel type, produced in 1969, the first concept drawing for a free standing spherical tank for LNG, without a secondary barrier. It was held that the design through a complete analytical investigation, supplemented by material tests, provided a leak before failure confidence level. The assertion was that should a crack occur, it would be detected before it grew to a critical size. On this basis the secondary barrier was omitted and replaced by a 'small leak' protection system. This took the form of a drip tray and splash barrier, where the insulation with vapour barrier acts as splash shield.

The cargo tank spheres, *see* Fig. 28, are designed to be prefabricated in 9 per cent nickel steel or aluminium alloy 5083 and located in the ship, either complete, or assembled from large sections aboard. The spheres are connected to a single cylindrical supporting skirt by a special equatorial ring comprising a section of the sphere and the upper part of the skirt. The lower part of the skirt is welded to the ship's structure and constructed in mild steel. Where the tanks are built in aluminium alloy, a bimetallic, intersected ring of aluminium and stainless steel, formed by roll bonding or explosion welding, provides the connection between the upper skirt in aluminium and the lower steel skirt.

After investigating various insulation materials and techniques, two particular systems were developed and used in Moss Rosenberg's own yards, as well as by one of its licencees. The first, referred to as the Panel System, consisted of rigid polystyrene panels, temporarily attached to the external surface of the sphere and then adhered to each other at the vertical butts and faces. The horizontal ends of the panels are separated by compressed mineral wool to allow for the

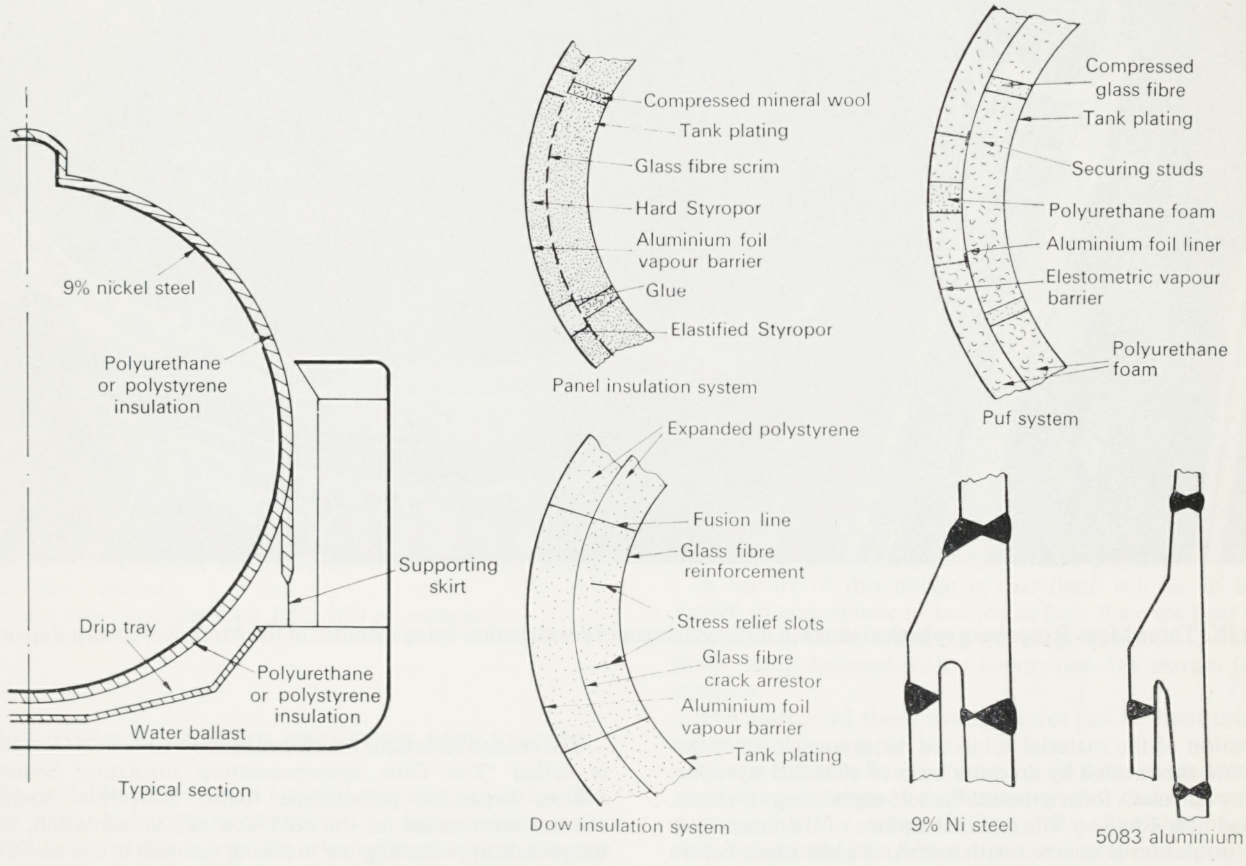


FIG. 28
Moss Rosenberg independent tank system.

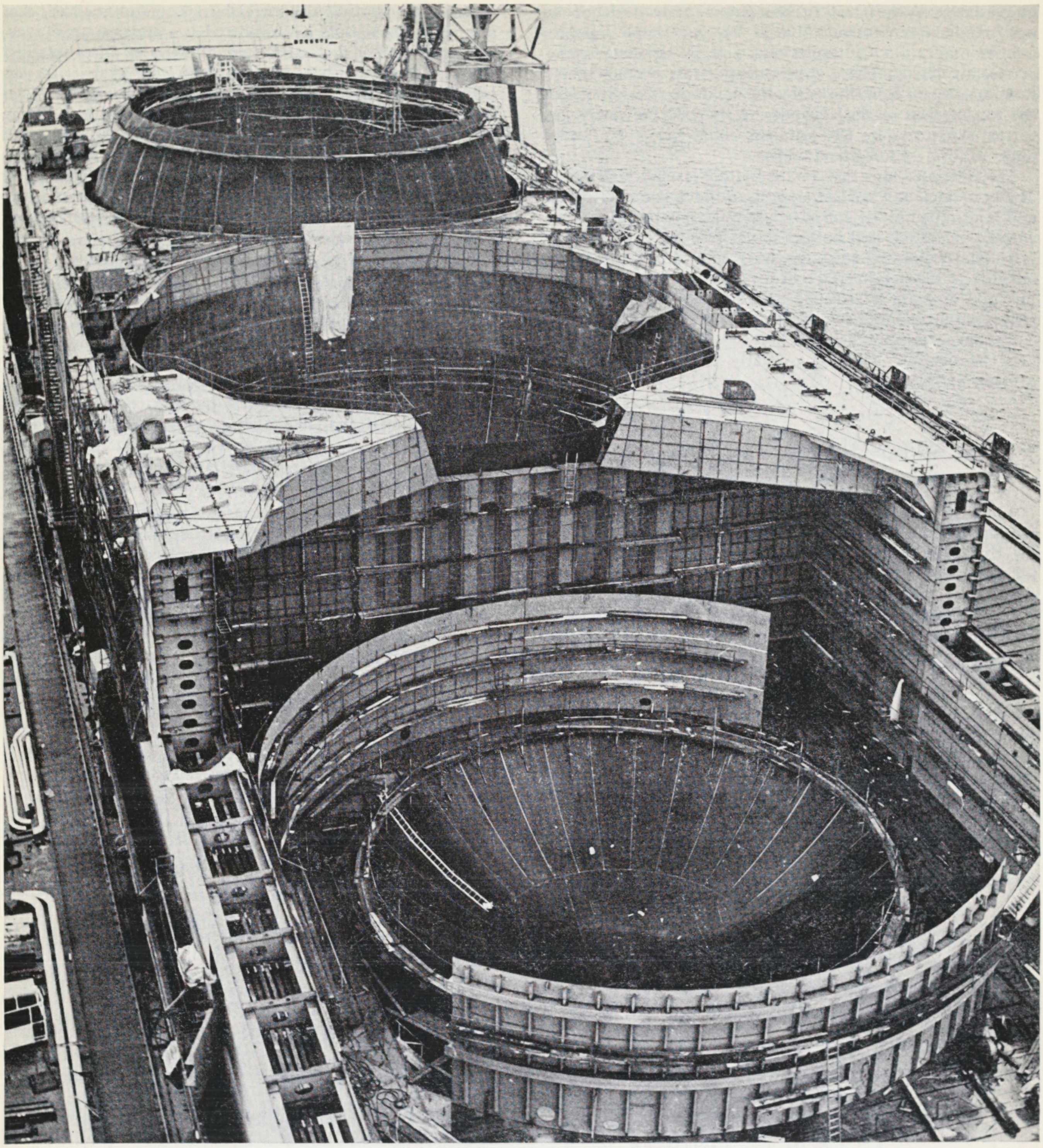


PLATE IX. Three Moss-Rosenberg spherical tanks in different stages of construction being installed at the Moss-Rosenberg shipyard.

contraction of the material subjected to cryogenic temperatures, and then sealed by an outer strip of elastified styropor, whereby all panels form a monolitic, self-supporting structure, attached near equator. The external surface of the inner layer of the insulation is covered with a fibrous glass mesh before the application of an outer layer, similarly shaped but less in thickness, to the inner layer with the spaces between individual blocks at the horizontal ends filled with elastified styropor, to form a crack barrier. These panels are prefabricated.

The second technique developed by Dow Chemical Company is called 'The Dow Spirogenerating Insulation System', utilizes expanded polystyrene foam. Tangential thermal stresses are created on the cold side of the insulation, of a magnitude approaching the breaking strength of the material. To relieve these stresses a heavy glass fibre reinforcing scrim is attached to the inner surface of the insulation material. This relieves the induced horizontal stresses with the vertical stresses being relieved by horizontal incremental slots. A

continuous thickness of expanded polystyrene is automatically spun spirally round the sphere. The automatic equipment is designed to fuse adjacent polystyrene strakes as the machine advances. The insulation system consists of two polystyrene layers separated by a crack arresting layer of glass fibre. An aluminium foil vapour barrier is automatically bonded to the outer surface of the insulation, during the log welding process, i.e. butt welding the prefabricated logs to form a continuous strake.

A third technique, which is used on ships delivered from and now under construction at General Dynamics consists of layers of foamed polyurethane attached to the spherical tanks and skirt by means of studs. Intermediate layers of aluminium foil provide additional vapour and splash barriers. Contraction of the inner layer is absorbed by compressed fibrous glass inserted between the section of the foam whilst that of the outer layer is absorbed by filling pieces of polyurethane, foamed in situ.

A fourth version, comprising panels of two different materials, will be used by Kawasaki Heavy Industries, Kobe. The total thickness of the insulation depends on the designed boil-off rate and is usually of the order of 200 mm. Provisions are made in this system for collecting smaller leaks of liquid cargo, using a drip tray fitted to the inner bottom. The tray is made of insulation material, with a protective cover, and extends vertically to about 2 metres at the sides. The insulation itself constitutes the spray shield, with drainage arrangements to the drip tray. Any leakage of liquefied gas is designed to run down the spray shield and into the drip tray. Special ejectors are provided to drain the tray. Recent development has brought forward a system comprising only a drip tray, sufficiently large to ensure continuous evaporation of possible leaks.

Permanent temperature sensors are located at selected positions in the spherical tank holds, to monitor any failure in the insulation.

Dry air, in place of nitrogen, or some other inert gas, is fed into the space surrounding the tanks (hold spaces). This, apart from the obvious cost saving, permits access into the space at any time without the need for gas freeing. A nitrogen gas supply (or other inert gas) is available at all times should remedial action be required in case of a leak. Nitrogen is continuously fed in the space between the tanks and the insulation to ensure dry atmosphere and reduce ice accumulation.

Regular sampling of the air verifies the integrity of the system.

Two of Moss Rosenberg's first LNG carriers, the 87 600 cu. metre *Norman Lady* and her sistership *LNG Challenger*, both built at the Group's Yard in Stavanger, Norway, employed 9 per cent nickel steel tanks. All other Moss Rosenberg ships have 5083–0 aluminium alloy tanks.

Ships delivered and equipped with this system total 1 117 500 cu. metres and include *Venator* and *Lucian* 29 000 cu. metres, *Norman Lady* and *LNG Challenger* 87 600 cu. metres, *Hoegh Gandria* and *Golar Freeze* 125 800 cu. metres, *Hilli*, *Gimi* and *Khannur* 126 300 cu. metres, and *LNG Aquarius*, *LNG Aries*, *LNG Capricorn* and *LNG Gemini*, all 126 750 cu. metres.

Ships now on order total 1 273 050 cu. metres.

4.10 OCEAN PHOENIX PRESSURE LNG SYSTEM

In 1960, Ocean Transport Group headed by Columbia Gas, New York, began the development of a high pressure multi-vessel containment system for which the prototype gas ship *Sigalpha* was built in 1962. In 1974, Ocean Phoenix Transport Inc., was set up to further the pressure concept, but using a more economical tank design operating at lower pressures.

The present system is therefore designed for the carriage of a single gas cargo of LNG and LPG at pressures of between 3 to 5 atmospheres, in multi-lobed tanks categorized as independent tank type C.

The multi-lobed tanks, *see* Fig. 29, are constructed in 9 per cent nickel steel or aluminium and formed at top, bottom and ends by part cylindrical lobes having a radius of, typically, 3.28 metres and supported by vertical and horizontal flat internal plates. The tank sides and corners are formed by segments of spherical domes also at 3.28 metres radius. At the intersection of three or more surfaces, special extrusions are used to reduce stress levels and to provide for all shell welds to be butt welds and therefore amenable to X-ray examination. Two access domes are situated at the top of each tank.

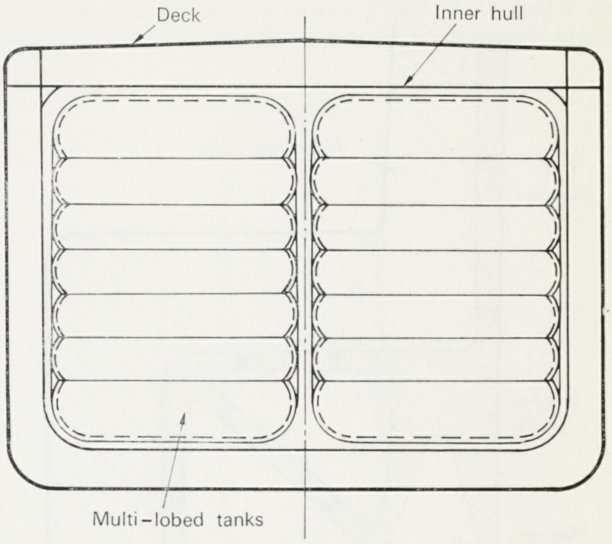


FIG. 29

Ocean Phoenix independent tank system.

The tanks stand free on resin bonded laminated wood chocks aligned with the tank nodes and the ship's transverse frames. The cargo tanks are centrally keyed against movement.

The insulation is non-load bearing and attached to the external surface of the lobes except when bridging the centre-line gap in a two tank configuration across the width of the ship. The insulation would take the form of a 165 mm thickness of polyurethane foam applied in panels. Alternatively, a perlite insulation system may be adopted.

The space between the lobes and the inner hull is inerted and a drip tray may be located below the tanks for the retention of liquefied gas in the event of small leakages. A gas detection system would be incorporated in this inerted space to monitor the integrity of the primary barrier.

A feature of this design is that there will be no boil-off vented to atmosphere or burned as fuel, since the heat leak is accommodated by allowing the cargo pressure to rise—the tanks being designed with a twenty-one day margin for this purpose.

The associated shore storage tanks can be built using the same general concept.

Ocean Phoenix have proposed a ship design and arrangement in conjunction with Burness Corlett and Partners, and subsequently, J. J. Henry Co. Inc., for a 171 400 cu. metre gas ship for which the Society has indicated its approval in principle for the tank design. As yet, no ships have been built to include this containment system, but an offshore application is currently being developed by an Ocean Phoenix Ellerman joint venture group.

4.11 SENER LNG CONTAINMENT SYSTEM

In 1970, the Bilbao based firm of consultant engineers and naval architects, SENER Technica Industrial y Naval, S.A., set up a design team of specialists from universities and research institutes to produce designs for low-cost large LNG carriers and facilities for building such ships.

The containment system, evolved during this design analysis, consists of self-supporting tanks of a spherical nature evaluated utilizing the 'SPHER' structural analysis computer programs, based on the Theory of Shells and Revolution, developed by Sener.

The system is similar to other spherical designs with the main difference lying in the support arrangement, *see* Fig. 30.

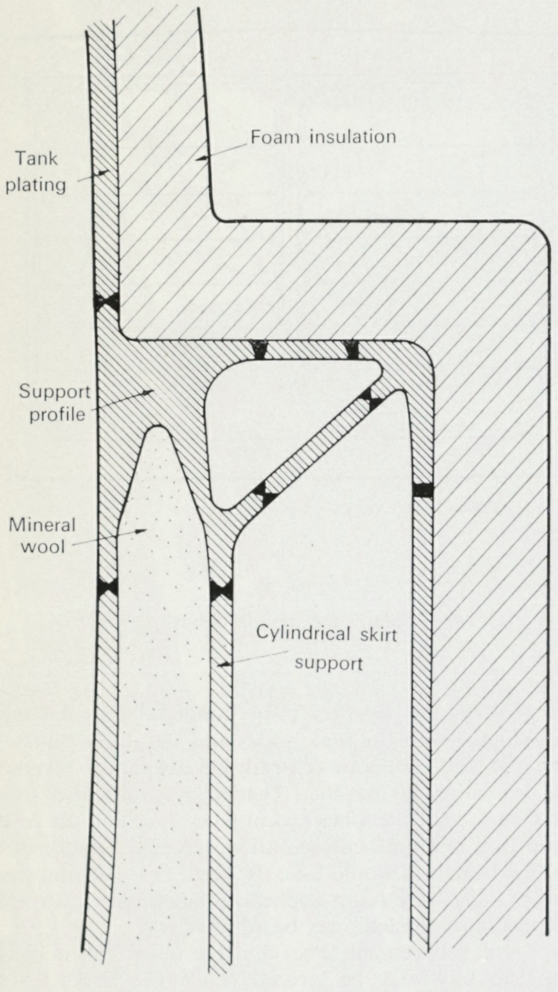


FIG. 30
Support for Sener independent tank system.

The system consists of an upper and lower hemisphere butt-welded to a continuous peripheral structure forming the support connection to the tank. The tank and the upper section of support are designed to be constructed of either 9 per cent nickel steel or 5083–0 aluminium alloy suitable for the carriage of liquefied gas at −162°C. A 126 000 cu. metre ship would comprise five 37 metre diameter spheres in 46 mm aluminium plating.

The upper part of the tank support consists of special profiles that form two connected cylindrical plate shells with the inner cylindrical shell profile forming part of the cargo tank sphere. The lower part of the support consists of the inner cylindrical shell fitted with vertical and annular stiffeners with the outer shell being formed by the stiffener flanges. The lowermost part of the inner shell support is welded to a pedestal structure whose purpose is to evenly distribute the the tank loads to the ship's structure.

The purpose of this double cylindrical support is to reduce the bending moments in the tank shell in the region of the peripheral connection between tank shell and support.

The spherical cargo tanks and inner and outer faces of the support are insulated by layers of either polystyrene or polyurethane foam. The wedge shaped space created by the connection of the cargo tank to the support is insulated using either glass wool or high density rock wool. The thickness of insulation on the support decreases from its connection to the tank to finish at a distance of about one third of the support height from its top. The insulation on the upper hemisphere is covered by stainless steel or aluminium plates to act as a vapour barrier between the cargo tank and ship structure.

Small leakage from the upper hemisphere is designed to drain through meridional channels on the inner side of the insulation and thence through small pipes in the annular plate of the peripheral structure to the inner surface of the support.

A drip tray constructed of low alloy steel is suspended from the lower part of the tank support. The upper face of this tray is insulated with the foam covered by a low temperature plastic layer bonded along the perimeter of the tray only. This layer acts as a tight barrier to collect small leakages from the cargo tank.

A suitable gas detection system is incorporated to monitor the inerted space between the spheres and the inner hull plating.

This system is fitted to the 5000 cu. metre LNG carrier *Sant Jordi* at present in service between Spain and Italy carrying ethylene.

In Spain, a new shipyard, CRINAVIS, Sistemas Navales y Criogenicos, has been specially designed for the construction of liquefied gas ships and this system is specified for their standard range of gas carriers (52 000 cu. metres, 126 000 cu. metres and 166 000 cu. metres).

It is understood that it is possible to utilize these spheres for ships up to 350 000 cu. metres.

4.12 TECHNIGAZ SELF-SUPPORTING AUTOCOMPENSATED TANKS

At the same period that Moss-Rosenberg were developing their spherical tank design Technigaz were in the process of evolving a containment design of similar concept for the carriage of LNG. This system was based on a mathematical analysis approach utilizing Flugge's Shell theory with the verification of the system carried out in tests on a 1500 mm diameter PVC sphere culminating in full scale structural tests on a 12 metre diameter sphere fitted to the first ship.

These spheres are categorized as type B tanks and are constructed in 9 per cent nickel steel. The main difference, in this design, lies in the arrangement of supports and keys, *see* Fig. 31. The tanks are supported by a system consisting of a parallelogram of rods and arms which are attached, at the top, to the underside of the deck, and, at the bottom, to the tank equator ensuring vertical support and allowing for free expansion with only a small portion of the hull strains being transmitted to the sphere. A similar arrangement of rods is employed at the transverse and longitudinal great circle positions to withstand the motions of roll and pitch. An alternative arrangement of keys and keyways is proposed with the keyways welded to the tank shell and the keys pinned to struts that are, in turn, pinned to the ship's inner hull.

The tanks and supporting arrangements are constructed in 9 per cent nickel steel with the welds being 100 per cent X-rayed.

After installation and testing of the spheres, the spaces between the tank shell and inner hull are filled with a granulate insulating material such as perlite. An alternative proposal is the fixing of a cellular plastic material, such as PVC or polyurethane foam, or mineral wool to the ship's inner hull. A gas sampling system is incorporated between the spheres and inner hull plating to monitor the primary barrier integrity.

At the present, only the *Euclides*, a 4000 cu. metre LNG carrier, has been fitted with this system and does not include a secondary barrier. For ships of larger capacity, an LNG retention bowl is to be provided, lining the lower part of the hold.

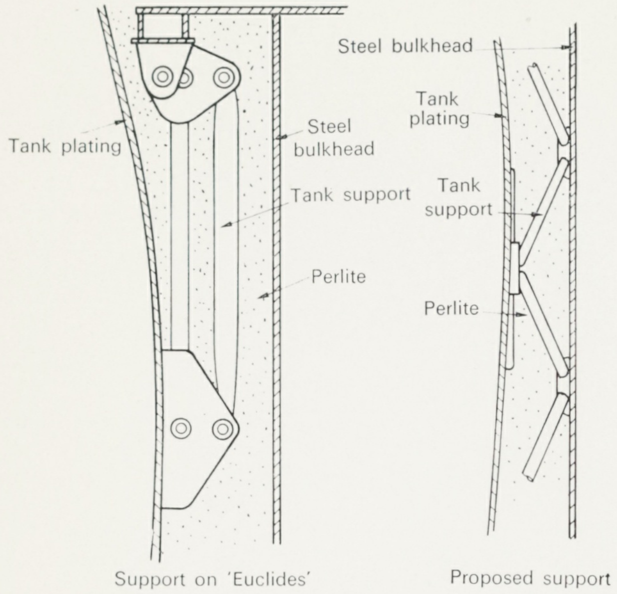


FIG. 31
Support for Technigaz independent tank system.

4.13 VEROLNAVE LNG CONTAINMENT SYSTEM

The Naval Project Development Company, Rotterdam B.V., is at present developing a free standing multi-vertical cylinder containment system for their proposed 330 000 cu. metre liquefied gas carrier designed for the carriage of methane at $-162°C$, 0.35 atmospheres. The designers are developing this system to meet the requirements for an independent tank type B.

The detailed structural analysis for this system subjected to the predicted load spectrum associated with a 330 000 cu. metre ship has been carried out by the Society's Advisory & Projects Group.

Each fully insulated cargo hold contains an 'integrated' tank consisting of 16 vertical self-supporting cylinder units with their own individual piping arrangements, *see* Fig. 32. The cylinders, measuring 11.8 metres in diameter by 34.8 metres in height, are constructed in 28/15 mm 5083–0 aluminium alloy, stiffened by horizontal rings and welded at the 1500 mm skirt plate base to a matrix of transverse and longitudinal girders attached to a bottom drip tray located on load bearing insulation adhered to the inner bottom plating.

The cylinders are inter-connected at their upper ends by specially designed elastic mounts to instill restraint against vibratory motion.

A 20 mm aluminium alloy bottom drip tray, acting as a partial secondary barrier, covers the entire surface of the insulation adhered to the hold's inner bottom plating and extends vertically for 1 metre at the inner side and transverse bulkhead. The movement of this tray, and, hence, the integrated tank is restricted by anchorages. These are located at the ship's centreline to prevent transverse motion, and at the

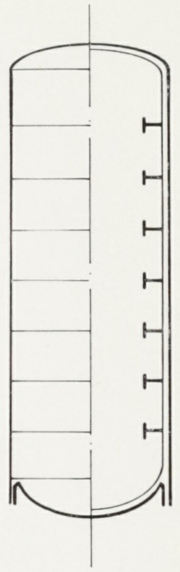


FIG. 32
Typical cylinder of Verolnave independent tank system.

mid-hold position to prevent longitudinal motion. Additional supports are situated under the perimeter of the girder matrix to sustain the high local loads in these regions.

Anti-lifting chocks are situated at the boundary of the base framework to which the cylinders are attached.

The inner surface of the cargo holds is insulated with a 350 mm layer of polystyrene foam. It is possible that during development the final design will incorporate polyurethane foam.

Leak detection devices will be provided to maintain the integrity of the primary barrier by sampling the inert gas in the space between primary barrier and inner hull.

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Lloyd's Register Technical Association

Discussion

on

Mr. A. G. Gavin's Paper

DESIGN AND CONSTRUCTION ASPECTS OF CONTAINMENT SYSTEMS FOR THE CARRIAGE OF LIQUEFIED GASES IN SHIPS

Paper No. 5 Session 1978-79

Hon. Sec. D. T. Boltwood
71 Fenchurch Street, London, EC3M 4BS

Discussion on Mr. A. G. Gavin's Paper

DESIGN AND CONSTRUCTION ASPECTS OF CONTAINMENT SYSTEMS FOR THE CARRIAGE OF LIQUEFIED GASES IN SHIPS

CONTRIBUTIONS

From Mr. E. Howey:

The Author has obviously researched the subject in considerable detail and I much admire the style and clarity of his paper.

However, I would seek a more precise detail from him with regard to his statement on page 2, second paragraph, which I quote in full—"It should be understood that all natural gases and gases described as L.P.G. occur as gases at Standard Temperature and Pressure, 0°C and 1.013×10^5 N/M^2, and that they require to be *pressurized and/or cooled* to maintain them in a liquid state." On the same page he accurately states that any increase in pressure of a gas, above its critical temperature, will not bring about the liquefication of the gas. I therefore consider that someone, in using his excellent paper for reference, may not obtain sufficient clarity from his earlier statement quoted. Would the Author please comment upon this important point?

I am not convinced that his statement concerning the so-called "rollover phenomenon" being unlikely to occur in ships is completely accurate. L.N.G. carriers spend a considerable amount of time in port and these ships can encounter extremely fair weather on passage, and the reference to seaways, as we know it, is not always applicable.

It is agreed that these ships may possibly suffer damage from grounding and collision. We must also remember that they can be subjected to fire and explosion hazards, due to, among other causes, human error, and we must be continuously alert against such happenings and adopt an extremely cautious approach when dealing with this type of ship.

From Mr. G. P. Smedley:

Mr. Gavin's paper is outstanding because it presents the different types of containment for the carriage of liquefied gases in ships. However, the title includes design. This must take account of legislation in force in the waters of maritime countries and the requirements of special and periodic surveys.

Most Owners require gas carriers that are acceptable in all territorial waters. In the past, the requirements of the U.S. Coastguards have been imposed upon those of Classification. The trend is for other countries to introduce legislation in the interests of safety where gas tankers are in confined waters, and are loading and discharging cargoes. In U.K. waters the recent Health & Safety at Work, etc., Act is likely to apply to "plants" on ships. Considering discharge from relief valves, the Act requires that hazardous materials must vent to a safe area. For hydrocarbon and poisonous gases it appears that venting to atmosphere may be unacceptable.

With reference to containments at about atmospheric temperature, experience on land with "as welded" steel tanks raised serious problems of stress corrosion cracking because of sulphide impurities in hydrocarbons. When the matter was investigated by the Society some years ago, it was decided that the Owners were responsible for the purity of the cargo. Today, the specifications for the purity of hydrocarbons are usually strict, especially on sulphur content. This may be the main reason for the freedom from cracking of containment at sea. Nevertheless at survey it is advisable to establish the purity of hydrocarbons that were carried in the tanks. Problems of stress corrosion cracking in ammonia vessels and tanks on land have also been serious. For some inexplicable reason the problem has not arisen at sea. Again it is advisable to examine carefully "as welded" ammonia tanks and vessels on ships.

In recent reports from the U.S.A., there appears to be some uncertainty about the integrity of certain types of membrane tanks if a gas tanker were in collision in confined waters. Has the Author any views on the matter?

Today membrane, spherical and cylindrical tanks are large and pose problems of examination at periodic surveys. The membrane tank is particularly difficult to examine because of the crimping of the membrane during construction (see Figs. in the Paper). How critical is a perforation of the membrane? If it could be hazardous, how should the surveys be effected to detect such faults?

Reference is made in the paper to leak detection by monitoring gas from ducts in the insulation. If the monitoring system indicates leakage of a tank containing cargo during a voyage, what action has to be taken? Is the Surveyor expected to check or calibrate the monitoring system during a survey? How is this effected?

It is required that new tanks are subjected to a water test. Is this normal for a membrane tank? How are leaks detected and what action has to be taken with reference to the insulation?

From Mr. W. H. Marsden:

My contribution is primarily aimed at encouraging the younger members of the Society to respond to the technical experience they meet in their work. Perhaps the Training Centre could emphasise this pattern by their encouragement to Trainees passing through the many courses that are held.

This paper could be considered in the category of a reference paper. It is getting more difficult to write a full technical paper on this subject since it requires the involvement of many H.Q. departments, representatives from which are present this evening.

Perhaps the Author could provide the information on the world fleet of L.N.G. Carriers under Section 4, as he provided under Section 3 for L.P.G. Carriers. No doubt a comparison with the relevant Section of the Register Book dealing with classed gas carriers will indicate why we should not be complacent with this subject and why we require to spread the latest knowledge to the field Surveyors.

The Society's involvement in Committees dealing with Gas Tankers mentioned in Section 5 of the paper, covers all aspects of Industrial Groups, Government Committees and International Meetings. The matter of safety is the main subject and how to achieve the highest standard in an industrial environment is the cause of these discussions. Classification Societies are always referred to by the various Administrations when matters of detailed technical involvement are required.

Under Section 6, following the paragraph heading referring to Type A independant tank, the word "classical" is used to describe the ship structural analysis procedures and this is illustrated in Fig. 5. Surely, this clearly indicates the progress made by the Society in the last decade when such analyses are referred to as "classical". Personal involvement in dealing with these analyses is more of a commitment than the word "classical" suggests.

The Author has clearly defined under Section 7 the containment system approval from the strength aspect. The approval time may be extended into years in view of the development programme which is entirely dependent on the Designers testing programme. The cost involvement of the Society is also extensive which includes the necessary witnessing of material testing by other Specialist Departments. It is difficult for Designers to appreciate the Society's costs especially as they are generally working on a final research budget trimmed to the last detail. It is equally difficult for Surveyors who locally deal with these Designers, to explain the Society's fees which are based on effective time involved with the Approval. The Author in his dealing of Section 7 must have assisted in the explanation of such fees. One project extended over ten years of development and, therefore, it will be understood that fees require to be considered at each approval stage, which may be contrary to the Society's general policy.

My final comments concern the most important aspect of any construction of containment systems and that is quality control. The first two paragraphs of Section 10 are therefore worthy of special attention and contain the correct emphasis. No doubt this subject will be the source of comment from the Surveyors in the field, where confirmation of control is the reality of their daily work.

My heartiest congratulations to the Author for a well-written and interesting paper.

From Mr. C. A. Gatt:

I wish to compliment and thank Mr. Gavin for producing this very valuable addition to the Association's list of technical papers.

Being personally involved in gas ships, I consider that it will be very useful as a reference paper not only to Surveyors engaged in the design and assessment of gas ships and their containment systems but also to those Surveyors in the field who need ready information on any of the numerous aspects covered in the paper.

The Society's involvement in gas ships started in 1934 with the *Megara*. Nothing was recorded after that for over 20 years until 1956 when a combined delegation from L.R. and the North Thames Gas Board went to the U.S.A. to discuss with the Constock Methane Corp. of Chicago, the feasibility of carrying methane to the U.K. This resulted in the 5000m^3 *Methane Pioneer*, which carried the very first commercial L.N.G. cargo by sea.

Today there are 54 gas ships classed with L.R. Whilst this represents only 10% of the total world fleet, our share of membrane ships is a considerable 37½%.

I refer to Section 5 regarding the I.M.C.O. Code and L.R. It is evident that the Society played a very important role in the formation of the present Code. The old Rules in D70 left a few grey areas which meant full use had to be made at that time of L.R.T.A. papers written by Messrs. Davies, Atkinson and Sumner and others for aspects like dynamic loading due to ship motions, supports and chocks and other details. These aspects are now fully covered by the present Rules. One major shift from the old Rules to the present Rules is the grades of steel requirements for ship structure subjected to low temperatures when emergency conditions prevail, that is in the case when the primary barrier fails. Previously Grade 'D' was permitted for temperatures down to minus 30°C and 'E' to minus 50°C. Today the Rules require grade 'D' down to minus 10°C and 'E' to minus 25°C. Perhaps some background to this dramatic change could be advised.

When discussing Rules and Regulations for gas ships, it is worth mentioning that National Authorities are becoming increasingly concerned with damage to life and the environment resulting from accidents involving the carriage of hazardous materials by sea. For example, the United States Coast Guard require ships trading with the U.S. or in U.S. waters to conform with Rules as laid down in the Federal Register. These run parallel with the I.M.C.O. Code but contain some additional requirements with regards to steel grades, production testing etc.

The Society has agreed to a procedure to enable a vessel to obtain a "Letter of Compliance" from the U.S.C.G. and this has been adopted for a number of ships.

I would like to refer to Section 6. It is stated that for membrane type tanks, the design vapour pressure should not normally exceed 0.25 bar. This requirement is obviously inherited from the tanker rule approach of 2.45 metre test head and would now appear rather superfluous since any pressure up to 0.7 bar can be accommodated in assessing the design of such containment tanks.

The approval of systems described in Section 7, is a very important feature in the Society's involvement with containment systems. This aspect necessarily entails lengthy and laborious assessment by various departments in H.Q. such as Hull Structures, Refrigeration and M. & Q.A. and the increased use of plastics and foams for insulation systems further compounds this assessment. In the last few years the Society has established an excellent rapport with manufacturers and this is essential when one considers the vast expediture involved in producing a system. Our procedural documents outlining requirements for system approval have proved invaluable to the manufacturers and certainly facilitates assessment. The Surveyor in the field should also be involved in witnessing as many tests as possible and all key stages of the testing programme

Finally, I would like to refer to Section 12 where the Author states that gas ships are just as susceptible to normal working abuse as other types of ship. How very true this is. The Society has ample statistics to substantiate this statement. They show that gas ships have suffered damage due to grounding, ranging alongside, collision, mal-operation by ship or terminal staff and other factors. It cannot be over stressed that today our assessment criteria must cater, not only for the integrity of the ship's structure from a commercial aspect but also, and predominantly so, for the prevention of accidents resulting in injury to personnel and damage to the environment.

From Mr. T. Kim:

I would like the Author's view on the present method employed in the calculation of dynamic loads due to ship motions (ref. Section 8 Design Criteria), particularly in respect of lateral motions. I understand that various Research Establishments and Universities are presently involved in developing non-linear theories to predict ship response in waves. Clearly, the Society should keep a close eye on the outcome of these studies in order to gain a possible means of improving the present calculation methods.

WRITTEN CONTIBUTIONS

From Mr. J. M. Ferguson:

My compliments to the Author on providing an extremely interesting, and I must emphasise "easily readable paper", which will provide a very useful reference document to all concerned.

I was particularly interested in the viewpoint "that in general terms the ship as a whole provides cargo containment despite failure to the ship. This has been clearly illustrated in a recent case of ship control failure on a V.L.C.C.

As the Author points out, ships carrying liquefied gases can sustain the same kind of operational damage as other ship types resulting in the side shell, which can also be the secondary barrier, being indented and damaged.

Whilst the design philosophy of containment systems which require secondary barriers demands that the effectiveness of both barriers be maintained, under normal operational conditions; there are, however, no means for providing an immediate visual indication during survey to advise which locations of side shell or other structure form part of the cargo containment system. With lesser familiarity of these ship types it would be possible, therefore, that a side shell could be treated as one constructed of normal shipbuilding materials and subjected to the usual loadings.

Would highlighting the external surface of the secondary barrier steelwork provide an answer to such a situation? Certainly, there may be benefits from the ship handling situation, as Port Authorities and possibly the Tug Captains would probably move with more care whilst handling a ship with "secondary barrier" painted along its sides.

From a survey point of view it is considered that as damage surveys are normally accompanied by internal inspections, the internal surfaces of hold spaces which form the secondary barrier should have their role clearly indicated at regular intervals.

Practical visual aids such as this, could aid in preventing the ship being thought of, as the Author states, "a separate unrelated entity from the containment system".

As indicated by the Author at the time of publication the internal insulation tank Types 1 & 2 were in the process of being considered by an I.M.C.O working group. In giving consideration to these tank systems the majority of the participants of this group felt that systems without interbarrier spaces and which rely on temperature sensing to detect primary barrier failure could not be recognised at this time. This represents a bias towards more traditional design principles which employ gas sensing as the primary means of detecting primary barrier failure. Systems, such as the Shell Polyurethane foam L.P.G. system where no interbarrier space exists, will not therefore comply with the I.M.C.O. Gas Code requirements upon the implementation of these new specific requirements.

Referring to the very descriptive appendix to this paper, I was surprised to see that the developers of the Ocean Phoenix pressure L.N.G. system describe it as a Type C tank system. While these tanks can be described as pressure vessels, they derive direct support through the ship's double bottom structure and thus are subjected to interaction with the ship, resulting in possible load concentrations which could vary dependent on ship's load condition. In addition, the arrangements for welding and changes of shape also require consideration, relevant to Type C "standards".

From Mr. B. Wilson:

The Author has provided the Technical Association with a fine summary of most of the systems, both currently in service and on the drawing board. I am sure that he must have been faced with editorial problems in the selection of material for this paper due to the availability of large amounts of data, texts, etc., on the various related aspects of the carriage of liquefied gases.

The behaviour and consequences of spillages of large quantities of L.N.G., both below and on the surface of water, and on the behaviour of "a vapour cloud" above the surface has been promulgated by several learned people and groups over the years without a great deal of agreement.

Whilst it is apparent that only "small scale tests" can be carried out for safety, ecological and economic reasons, to attempt to deduce all the consequences of "large spillages" is perhaps questionable. For instance, to assume that the wind direction prior to a "large spill" will prevail during dispersion is decidedly speculative due to the possibility of rapidly changing iso-barometric conditions in the vicinty.

Can the Author confirm (or otherwise) that it is still the designer's intention, when L.N.G. is to be carried in the Bridgestone Semi-Membrane System, that the primary membrane is, in fact, installed "oversize" at ambient temperature in order to partially cater for contraction when the membrane is cooled to cargo temperature.

From Dr. W. D. Morris:

I would like to congratulate the Author on his excellent paper.

On a question of internal dynamic loads due to sloshing, what aspects, if any, does the Author consider deficient in the appraisal of L.N.G. tanks in the light of what has been said regarding system failures; and does he believe that further model testing would be advantageous?

AUTHOR'S REPLY

Initially I would like to take this opportunity of thanking those colleagues who have contributed to the discussion.

To Mr. E. Howey:

I have stated in the Section "The Nature of the Product" that ". . . above a certain temperature, known as the critical temperature, any increase in pressure will not bring about the liquefaction of the gas". In the case of the Liquefied Petroleum Gases all the critical temperatures are above normal ambient temperatures, the lowest critical temperature being for Ethane at +32°C. It can be seen from this that for all L.P.G.'s, the gas may either be fully pressurized at ambient temperature, fully refrigerated at atmospheric pressure, or semi-refrigerated/semi-pressurized to maintain the gas in a liquefied state for carriage.

The phenomenon of "roll-over" has not occured, to the Author's knowledge, in a gas ship, or at least not on a scale which has created an increase in vapour pressure which has resulted in damage to the containment system. Ships normally load from one port so that the possibility of two cargoes of differing densities being loaded into the same tank is unlikely. A prolonged stay in port would provide the necessary ingredient for this particular danger.

To Mr. G. P. Smedley:

It is notable that legislation introduced by Governments for application to gas carriers trading in their territorial waters is imposing regulations in addition to those of Classification. A case in point is the recent publication of the regulations relating to the carriage of anhydrous ammonia through the Kiel Canal. These regulations require compliance on aspects such as design environmental temperatures, size of reliquefaction plant, cargo tank insulation and type of tank (i.e. A, B or C). These requirements are in addition to the I.M.C.O. certificate of fitness.

With reference to the carriage of cargoes at about atmospheric temperature, evidence indicates that a gas which has a high sulphur content generates hydrogen sulphide which can cause caustic embrittlement of metal, thus initiating cracking. The area most prone to this being the welds. This situation is recognised by the Society and the recommendations to minimise this risk is stipulated in the Gas Ship Rules Notice No. 3 chapter VI, paragraph LR3.

An analogous parallel to the collision of a gas tanker employing membrane tanks in confined waters is the recent severe grounding of an 125,000 cu. metre gas tanker at a speed of 15 knots. In this case the double bottom was damaged over three tank lengths such that the bottom longitudinals were in contact with the inner bottom longitudinals. This resulted in severe local deformation of the tank primary membrane with no loss of cargo recorded.

It is known that certain membrane systems are operating at a higher percentage of the L.E.L. than stipulated in the I.M.C.O. Code. For these ships, the percentage of gas in the interbarrier spaces is consistantly monitored and reported to assess the significance of the leakage and, therefore, the perforation of the membrane. In this situation, where no increase in the gas in the interbarrier spaces is recorded, no action has been taken. Should this situation deteriorate then this becomes an emergency condition and should be treated accordingly. The study of the records relating to the gas monitoring of the tanks over the preceding period should warn the Surveyor of any deficiency in the membrane.

If the monitoring system indicates a leakage of cargo into the interbarrier spaces during a voyage, the ship should, circumstances allowing, continue to its port of destination where the cargo should be discharged, the leak located and repaired. This action is, of course, dependent upon the size of the leakage involved. If the percentage of cargo indicated by the monitors in the interbarrier space is rising at a slow rate, it can quite readily be monitored during the period up to the time of discharge with no immediate action necessary. In more serious cases where the interbarrier spaces are flooded with cargo resulting in the expulsion of gas through the relief valves, the master has the ultimate option of discharging his cargo overboard.

After the discharge of the cargo at the port of destination, the containment tank and interbarrier spaces must be gas freed, the leak located by recognised leak tests, repaired in accordance with the approved procedure for that containment system and then re-tested before the ship can be recommissioned.

The monitoring system must be recalibrated by the Surveyor, as indeed it is at each annual survey. This is accomplished by means of span gases i.e. standard gas samples in bottles that can be attached and fed through the monitoring equipment.

It should be noted that a breach of the primary barrier results in a secondary barrier condition. The secondary barrier is designed to the standards applied to the primary barrier and, therefore, the term "emergency condition" should be viewed in this light.

The I.M.C.O. Code for Gas Ships states that "In ships fitted with membrane or semi-membrane tanks, cofferdams and all spaces which may normally contain liquid and are adjacent to the hull structure supporting the membrane should be hydrostatically or hydropneumatically tested in accordance with recognised standards". In keeping with this, the membrane tank itself is not hydrostatically tested but the adjacent spaces are before the application of the membrane system. For membrane tanks, quality assurance measures, weld procedure qualification tests, design details, materials, construction, inspection and production testing of components should be to standards developed and approved during the prototype testing programme.

The detection of leaks in the membrane is accomplished by using "sniffers" to detect a trace gas, fed under pressure, behind the membrane. The membrane joints are also tested during construction by vacuum box techniques.

The repair of the insulation and membrane in the case of damage or leakage should be in keeping with the Manufacturer's procedures, developed and approved during the prototype testing stage. It should be noted that the insulation provides a thermal barrier and is not designed as a liquid barrier.

To Mr. W. H. Marsden:

I should like to thank Mr. Marsden for his notable comments especially in clarifying the Society's long term involvement in the approval of the containment systems during their considerable development period.

The Society's share of the World L.N.G. Fleet stands at 22½% and its share of membrane ships, stated by Mr. C. A. Gatt in his discussion, stands at present at 37½% although our share of the total World Fleet, both L.N.G. and L.P.G., stands at 10%. The Society has 12 L.N.G. ships to class out of a total L.N.G. fleet of 54 ships.

I should like to add my voice to Mr. Marsden's in encouraging the younger members of the Society in writing technical papers not only for their benefit to the Society's Surveyors but also, on a personal basis, for the educational opportunity that is presented.

To Mr. C. A. Gatt:

The rules regarding the grades of steel for particular service conditions were reviewed for inclusion in the 1975 I.M.C.O. Gas Code by the Member Countries from the Unified Requirements produced by I.A.C.S. These can be seen as a more cautious approach to those previously seen in the 1975 Rules.

It is interesting to note that the present proposal to I.M.C.O. regarding grades of steel have advised that Grade D, up to 10 mm, and Grade DH, up to 20 mm, be approved for temperatures down to −30°C, and that Grade E, up to 20 mm, be approved down to −50°C. This bears a marked similarity to our 1975 Rules.

The I.M.C.O. Code for Gas Ships states that for membrane ships the design vapour pressure should not normally exceed 0.25 bar, but this may be increased to 0.7 bar if the hull scantlings are increased accordingly. In membrane ships, structural testing is confined to the supporting structure and involves the hydrostatic testing of the spaces adjacent to the cargo containment system.

Concerning the test head to be imposed for pressures above 0.25 bar, consideration should be given to the weaker elements of the structure being tested and increases in the test head above 2.45 metres could result in scantlings of the side, bottom shell and attached longitudinals being increased.

The practicality of increasing the design vapour pressure above 0.25 bar, bearing in mind recent damage cases, could only be assessed for existing membrane systems by further prototype testing.

To Mr. T. Kim:

The scantlings of the containment system and/or supporting structure are derived using dynamic loads predicted as occurring once in the ship's life, taken as 20 years. These loads are applicable to all surfaces of the tank at any one instant and are so applied in full tanks for the derivation of scantlings and structural analysis procedures. The actual prediction is that these loads will occur once in 20 years, not that each surface will be loaded to the full pressure predicted at the same time. This criteria would appear to be severe and justified due to the nature of the cargo carried in these ships.

It is interesting to note that the results of sloshing calculations carried out for partial cargoes have predicted impact pressures, in each case, that are less than the calculated dynamic design loads that form the basis for scantling derivation. The sloshing calculation procedure was formulated from model tests on smooth walled vessels.

To Mr. J. M. Ferguson:

I should like to thank Mr. Ferguson for his contribution to this discussion especially to record the majority decision reached by the I.M.C.O. Working Group considering the inclusion of Type 1 and 2 Internal Insulation Containment Systems in the Code and the bearing this will have on particular current systems of this type.

I believe that highlighting the external surface of the secondary barrier would improve the effectiveness of this barrier during normal operational duties by increasing the awareness of the crew and port personnel as to its nature and location. In addition, it would benefit the Society's Surveyors during survey should they not be familiar with the particular ship under their responsibility.

The marking of the main deck with say "dotted lines" and the words "secondary barrier" would indicate to the Surveyor the extent of special quality steels and aid him in the approval and inspection of any additional structures or repairs that may be proposed in this area. Similarly, the marking of the internal surfaces of the ship's structure with the words "secondary barrier" would also serve this purpose.

To Mr. B. Wilson:

The section dealing with the consequences and behaviour of gas in uncontrolled circumstances has been extracted from the studies made by the U.S. Bureau of Mines who undertook the investigations on behalf of the U.S. Coastguard.

It is still the designers intention with the Bridgestone Semi-Membrane system that the primary membrane is installed oversize to partially cater for the contraction of the membrane when it is cooled to the cargo carriage temperature.

To Dr. W. D. M. Morris:

The instance of systems failure resulting from excessive impact pressures due to sloshing is normally reduced by the application of restrictive filling limits derived for L.R. Classed ships using the Society's computer programme for the calculation of wall pressures in smooth rectangular tanks due to the movement of liquids.

From the data available it is considered that this programme is based on an exceedance level of about 1%, in that for a given number of sloshing cycles, 1% exceeds the value predicted by the programme. The peak values that occur within this 1% exceedance may comprise pressures in the order of $2\frac{1}{2}$ to 3 times the magnitudes predicted.

This programme was developed for steel structures, and holds true for such, since these peak magnitudes only occur for a fraction of a second allowing for the flexibility of the steel structure to absorb and distribute the load.

In the damage cases stated, a plywood box that is rigidly supported by internal plywood frames, narrowly spaced, had, by virtue of its rigidity, to sustain these peak magnitudes. Plywood, as a structural material, has no plastic range and the high impact pressures, within the exceedance range of the Society's programme, resulted in the rupture of the plywood surface and the loss of the internal insulating material.

It is the opinion of the Author that the investigation of sloshing pressures for containment systems whose partial fillings are contemplated must take into account these exceedance magnitudes not only at the ship application stage but also at the prototype testing stage.

In considering the phenomenon of liquid motion in slack tanks, there is a degree of uncertainty with regard to the behaviour of liquids and consequent pressures at higher filling levels.

In the case of recent damage cases, the damage occurred at the top corner of the tank whilst at a 96% filling level.

As you suggest therefore, there would appear a need for further practical evaluation to clarify this situation.

In addition, it is the Author's opinion that, in his experience with the calculation of sloshing pressures in independent tank systems, the effect of the internal primary stiffening structure and the narrowing of the tanks could be more fully investigated.

AUTHOR'S FOOTNOTE

It has been brought to the Author's attention that Hawthorn Leslie Shipbuilders were involved in pioneering work in the field of the fully refrigerated L.P.G. carriers with the 11,751 cu. metre *Clerk Maxwell* built in 1966, with three independent tanks, and then in 1967, the 11,474 cu. metre *Mariano Escobedo* and 3499 cu. metre *Petroquimico 1*.

It is stated on page 10 of the paper under "the approval status of the submitted containment systems" that the Ocean Phoenix system has been granted "Approval in Principle". It should have been stipulated that this system has only been considered for "Approval in Principle".

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DESIGN AND CONSTRUCTION ASPECTS OF LAND BULK STORAGE SYSTEMS FOR CRYOGENIC AND LOW TEMPERATURE REFRIGERATED GASES

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GUEST LECTURE

Paper No. 6. Session 1978-79

Any opinions expressed and statements made in this paper and in the subsequent discussion are those of the individuals.

Hon. Sec. D. T. Boltwood
71, Fenchurch Street, London, EC3M 4BS

DESIGN AND CONSTRUCTION ASPECTS OF LAND BULK STORAGE SYSTEMS FOR CRYOGENIC AND LOW TEMPERATURE REFRIGERATED GASES

by W. P. CARTER, B.Sc., M.Sc., C.Eng., F.I.M., F.Weld I. and W. A. ROWLEY, B.Sc., E.Eng., F.I.Mech.E., M.B.C.S.

1. SYNOPSIS

The paper details some important design and construction aspects which must be considered in the storage of liquefied gases in bulk form. Current design rules and construction requirements in the United Kingdom and the United States are compared and significant differences are highlighted. The importance of welding and metallurgical aspects of tank construction are discussed and the need for minimum levels of fracture toughness in materials is considered.

Testing requirements with emphasis on mechanical overstressing are also discussed. The principal factors in the design of insulation systems are considered and other special features, including the use of suspended decks, are detailed.

Emphasis is placed on future trends and requirements with particular regard to safety and environmental considerations. Attention is drawn to the essential co-operation required between user and manufacturer if detailed engineering design and operational safeguards are to provide safe and economic storage for future installations.

2. TABLE OF CONTENTS

3. INTRODUCTION

Bulk storage systems for liquefied gases fall into two categories, pressurised and refrigerated systems, which can be understood by reference to the table of product properties (Table 1). It is not intended to deal with the first system in this paper but it needs to be introduced as a preliminary to the second with which this paper is concerned.

Some gases are readily liquefied by pressure alone and are often stored as liquids in pressure vessels at substantially ambient temperature conditions. These may take the form of spherical units or horizontal bullets and a number of papers have been presented on such storage systems (1,2). Gases which can be so liquefied, stored and transported in this category include butane, propane and anhydrous ammonia.

However, for current bulk storage requirements for process feedstock purposes, bulk terminal export/import facilities and for peak shaving strategic stores, pressure vessels are extremely expensive in prime cost, running cost and ground utilisation. The last is expensive as pressure vessels are limited in size by pressure/material thickness considerations.

This paper is concerned with those gases which have their critical temperatures below normal ambient temperatures, and require refrigeration before conversion to the liquid state and storage at essentially atmospheric pressure. Those gases mentioned previously which can be stored as liquids under pressure are usually bulk stored in the refrigerated form in single envelopes with externally applied insulation and external safety walls and/or bunds. Those which cannot be liquefied without a greater degree of cooling are stored in double envelopes with interspace insulation again with external safety walls and/or bunds. Liquids such as ethane, ethylene, methane and oxygen fall into this second grouping.

The first bulk refrigerated tank stores in this country were for tonnage oxygen plants in steel works production units. In the majority of cases, the inner envelope was made from stainless steel and even today, for units up to about 15 metres in diameter, stainless steel can be the economically preferred containment material.

In the late 1950's with methane more readily available and developments in transportation techniques across the oceans (3), there was a need for much larger single storage units both at the importing as well as the exporting terminal. Single units have been installed in the U.K. with a product capacity of 50,000 cu.metres (see Plate No. 1) but units more than twice this capacity have been successfully built and operated in other countries.

One of the first refrigerated liquid natural gas bulk storage installations was built at the East Ohio Gas Company, U.S.A., and its failure in 1944 held up progress generally in this field for a number of years. The first refrigerated propane storage scheme to be commissioned was delayed until 1956 at Atlanta Gas and Light Company in Georgia, i.e. less than 25 years ago! Today there are several hundred major storage schemes in everyday use for butane, propane, ethane, ethylene and methane, as well as ammonia, chlorine, nitrogen and oxygen bulk refrigerated

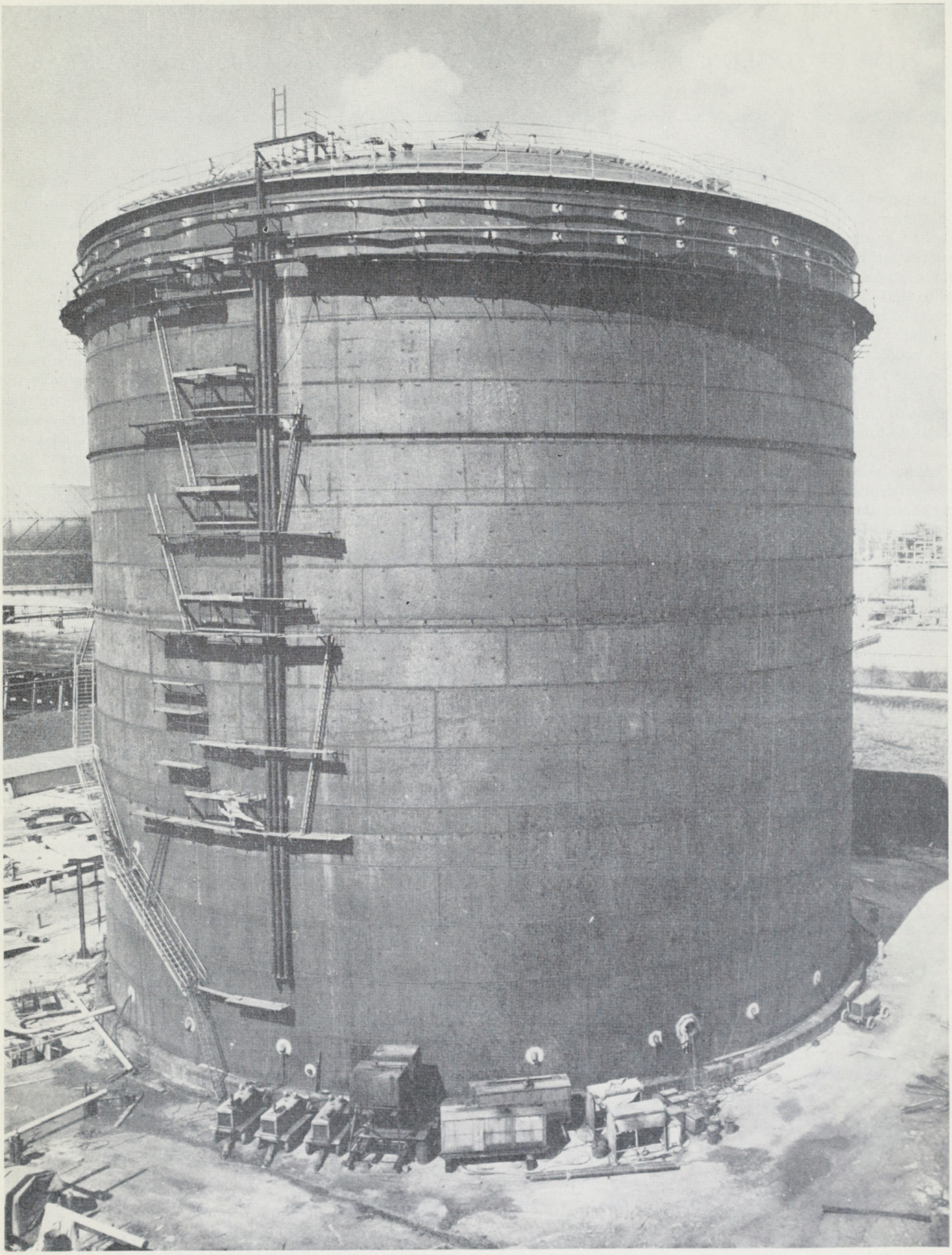

PLATE No. 1 50,000 CUBIC METRE L.N.G. TANK AT PARTINGTON (B.G.C.)—DOUBLE WALL WITH INTERSPACE INSULATION

TABLE 1

PRODUCT PROPERTIES AND STORAGE SYSTEMS

	Approx. Specific Gravity	Critical Pressure ATM.	Critical Temperature °C	Boiling Point °C	Pressurized Systems Category	Liquefaction Systems Category
n-BUTANE	0.60	37.5	152.0	−0.5	Bullets and Spheres	Single Walled Tanks
Iso-BUTANE	0.60	36.0	135.0	−12		
PROPANE	0.59	41.9	96.7	−44.5		
AMMONIA	0.68	113.0	132.2	−33.4		
ETHANE	0.55	48.2	32.27	−88.6	Non Feasible	Double Walled Tanks Interspace Insulation
ETHYLENE	0.57	51.2	9.4	−104.0		
METHANE	0.47	45.4	−82.6	−161.5		
OXYGEN	1.14	50.8	−118.2	−182.9		
NITROGEN	0.81	33.9	−146.8	−195.8		

storage systems. The continuing "energy crisis" combined with increased requirements for structural integrity, environmental protection, and public safety is leading to a significant re-evaluation of storage systems.

It is essential to draw attention to the good engineering and operational safeguards which must be practised in the storage of bulk refrigerated gases, notwithstanding the extremely good safety record of such installations. This paper, and hopefully the ensuing discussion, will draw out the needs of conceptual arrangement, design detail, material selection, quality standards and safety requirements which together are essential to an understanding by all who are involved in the business.

4. DESIGN AND CONSTRUCTION

4.1 Overall Design Requirements

The design of both single-wall and double-wall storage tanks at low and cryogenic temperatures is strongly dependent on a detailed appreciation of the manner in which the storage installation is to be operated and the behavioural characteristics of both metallic and non-metallic materials.

It is the responsibility of the user to give to the design team sufficient details of the particular installation such that the designer can bring together the necessary disciplines of expertise, thereby ensuring that the design meets all the anticipated circumstances during the life of the installation. It is the responsibility of the user to have a reasonable grasp of the design principles involved and the responsibility of the designer to understand the operational circumstances to which his design will be subjected.

Whilst the "shopping list" is considerable and may vary on a job-by-job basis, it should include the following minimum considerations:

- Geographical location both general and particular.
- Tank capacity (either by volume or dimensions).
- Load bearing ground conditions.
- Product specific gravity.
- Product constituent components.
- Min/max design temperature conditions.
- Max/min design pressure/vacuum conditions.
- Number and magnitude of thermal cycles.
- Size, number, type and location of appurtenances.
- Maximum boiling rate permitted.

The designer thereafter needs the following disciplines of expertise available to him, together with an ability to converse in such terminology with:

- Mechanical/Structural Engineers, with associated understanding of Stress Analysis, Computer Systems Analysis and Fracture Analysis.
- Electrical Engineers, with particular reference to foundation heating systems.
- Electronic Engineers, with reference to instrumentation.
- Civil Engineers, with reference to foundations.
- Chemical/Process Engineers, with reference to insulation systems, product behavioural patterns and process criteria.
- Welding and Metallurgical Engineers, with reference to materials of the primary structures.
- Quality Assurance/Quality Control/Inspection Engineers, with a full involvement in the Quality Plan and its method of implementation.
- Production and Construction Engineers.

Armed with this capability, the designer can then consider the various Standards which have been developed to cover the minimum requirements for low pressure storage tanks for refrigerated products down to −50°C (BS 4741 (4) and API 620 Appendix R (5)), and for liquefied gases for temperatures not lower than −196°C (BS 5387 (6) and API 620 Appendix Q (7)). These rules constitute a comprehensive appreciation of the functional design technology, emphasise the joint and separate responsibilities of the purchaser and designer/fabricator and reflect the attitude which the user and supplier industries have for the safety and integrity of such installations.

4.2 BS 4741 and API 620 Appendix R

4.2.1 General

It should be emphasised that the rules contained in these two Standards constitute a guide to the minimum requirements for materials, design and construction matters.

Such tanks may be designed as a single wall insulated tank, or a double wall tank consisting of an inner tank for storing the refrigerated product and an outer tank enclosing an insulation space, surrounding the inner tank. In a double wall tank the outer tank is not required to contain the product and differences in materials, design and testing requirements exist between the inner and outer tank.

The design of refrigerated storage tanks down to −50°C is similar to oil storage tanks and have usually been built of the single wall type with external insulation as shown in Figure 1.

The two Standards cover material selection, the principal design loadings and parameters to be taken into account, inspection/testing requirements, insulation, pressure and vacuum relief devices, and foundations.

4.2.2 Materials

The materials requirements in API 620 App. R are based on minimum mechanical properties at the design metal temperature. Components are divided into those whose failure would result in leakage of the liquid being stored, exposure to the refrigerated temperature or subject to thermal shock (PRIMARY COMPONENTS), and those whose failure would not result in the leakage of liquid (SECONDARY COMPONENTS).

The basis of material selection for primary components (shell plates, bottom plates, mountings, etc.) is shown in Table 2.

The materials requirements in BS 4741 have been based on the results of a number of notched and welded Wells Wide Plate Tests (WWP) of carbon and carbon/manganese steel plates and assessments of practice to date permitted in

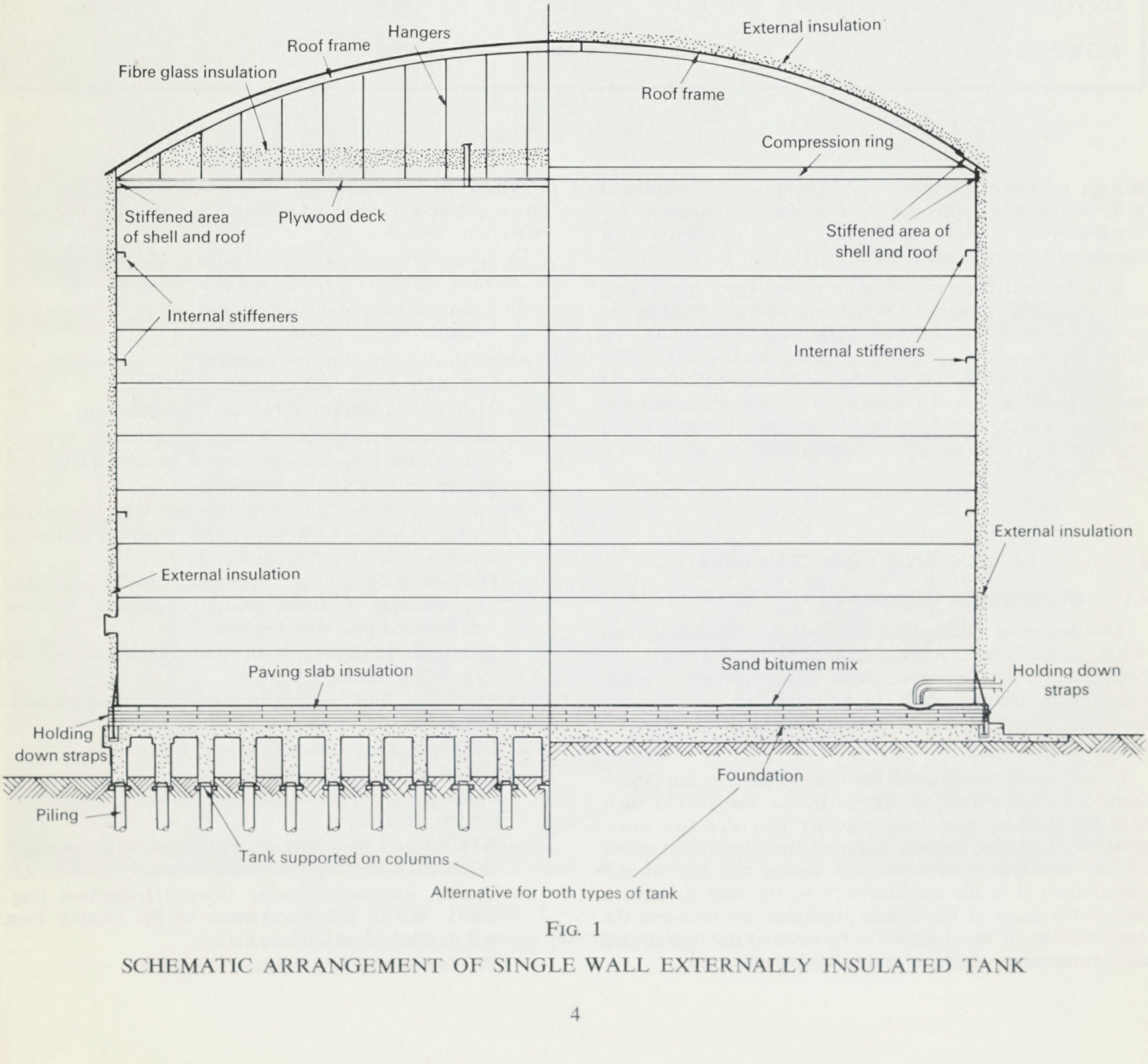

FIG. 1

SCHEMATIC ARRANGEMENT OF SINGLE WALL EXTERNALLY INSULATED TANK

other national Standards. Notch toughness of material, material thickness, flaw size, and degree of local embrittlement at the tip of pre-existing defects are believed to be the significant parameters in determining fracture initiation behaviour. The Standard proposes material selection based on Charpy V (C_v) energy values for given thicknesses and design temperatures down to $-50°C$ based on tests in which through-thickness defects up to 10mm size were required to withstand approximately four times yield point strain without fracture initiation. Various benefits are accorded to overstressing, post-weld heat treatment and increased inspection.

The rules governing material thickness, C_v notch ductility, minimum design temperature, degree of overstressing, etc., are shown schematically in Figure 2.

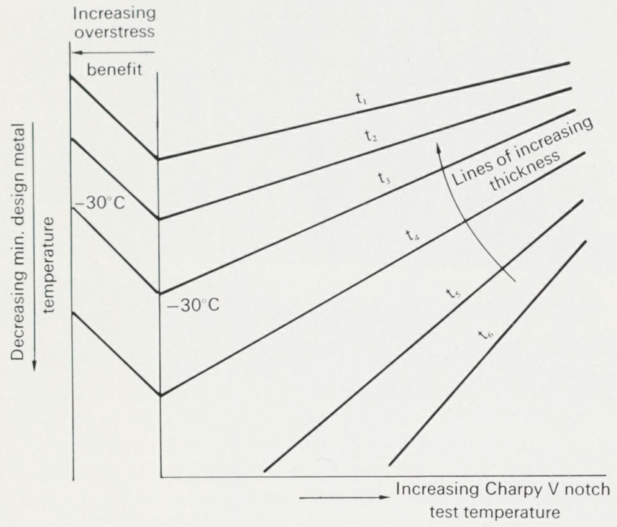

FIG. 2

BASIS OF MATERIAL SELECTION FOR BOTTOM, SHELL AND ROOF PLATES AND STRUCTURAL SECTIONS—BS 4741

4.2.3 **Design Stresses**

The maximum allowable tensile design stress in any shell plate required by BS 4741 is the lesser of 260 N/mm² or 0.67 x minimum specified yield strength of the shell plate material. API 620 App. R requires that the maximum tensile design stress shall not exceed 0.30 x UTS or 0.60 x Y.S. of the shell material at any location for any combination of the loadings taken into consideration.

The British Standard imposes no penalty on the allowable design stress for structural steel qualities but does impose a penalty on the allowable design temperature. If structural qualities are impact tested per every rolled plate, no penalties are imposed.

However, where materials are tested on a structural basis in API, design stress values must be reduced by 8%.

Due cognizance must be taken of such factors as the specific gravity of the stored liquid, internal and external pressure, roof live loads, wind loads, corrosion allowance, etc.

As will be seen later, it is recognized that localized shear and secondary bending stresses may exist in the shells of tanks as built and the prescribed test loadings may result in localized reshaping. This is acceptable provided that the magnitude is not so severe as to cause reversed yielding upon release of the test loading. The importance of overstressing will be discussed in a later section.

4.2.4 **Inspection**

API requires 100% radiography of all butt welded seams in excess of 1.25″. When a joint factor of 1.0 is employed and thicknesses are less than 1.25″, 100% radiography of butt welded seams is required, except that only those parts of horizontal seams at the junction with vertical seams require examination. All annular plate butt welds and joints between compression rings and sections of shell stiffeners designed to the API rules must be of butt welded construction.

BS 4741 does not require 100% radiography and/or other NDT methods in order to adopt a joint factor 1.0. Whilst up to 10% inspection of vertical joints and 2.0% inspection of horizontal seams together with all T joints fulfills the minimum requirements of the standard, increased levels of inspection are almost invariably adopted in clients' specifications. All fillet welds and butt welds in mountings which cannot be examined by radiography require crack detection before hydrostatic testing.

4.3 **BS 5387 and API 620 Appendix Q**

4.3.1 **General**

These Standards dictate the minimum requirements for material selection, the principal design loadings and parameters to be taken into account, fabrication, inspection/testing for the storage of liquefied gases down to $-196°C$. BS 5387 covers a range of gases including ethane, ethylene and methane.

BS 5387 relates only to double wall tanks while API 620 App. Q covers single and double wall construction.

It should be appreciated that the products listed above are invariably stored in double wall tanks with the inner tank containing the refrigerated product and the outer tank designed for essentially ambient conditions as an envelope to retain the insulation and purge gas, and to prevent the ingress of airborne moisture.

It is emphasised that the current rules incorporated in these Standards do not provide for an outer tank design to act as a containment for the inner tank refrigerated liquid under any circumstances.

Various designs of inner tank containment have been adopted where a fixed metal roof provides a complete barrier for both liquid and vapour between the inner and outer tanks. Designs incorporating a suspended deck to the inner tank permit free passage of vapours in the gas spaces of both tanks; thus, the outer tank contains the vapour pressure of the inner tank liquid.

Typical designs of double wall containment and insulation are shown in Figure 3.

4.3.2 **Materials**

Outer tank materials covered by the requirements of API 620 and BS 2654/BS 4741 where appropriate, are primarily exposed to atmospheric temperatures.

The principal materials adopted for the inner tank and primary component construction are listed in Table 2. It can be seen that austenitic stainless steels, 9% nickel ferritic steel and certain aluminium alloys, all of which exhibit excellent ductility at cryogenic temperatures, are incorporated in both rules.

API 620 Q allows the use of a $5\frac{1}{2}$% Ni steel (A645) which does not appear in the BS document. However, materials to such specifications are not precluded, provided such materials have the necessary properties and the purchaser and manufacturer are in agreement.

Neither Standard requires impact testing of austenitic stainless steel and aluminium materials.

Transverse C_v impact testing is required in API for the ferritic 9% nickel and $5\frac{1}{2}$% nickel steels, which must

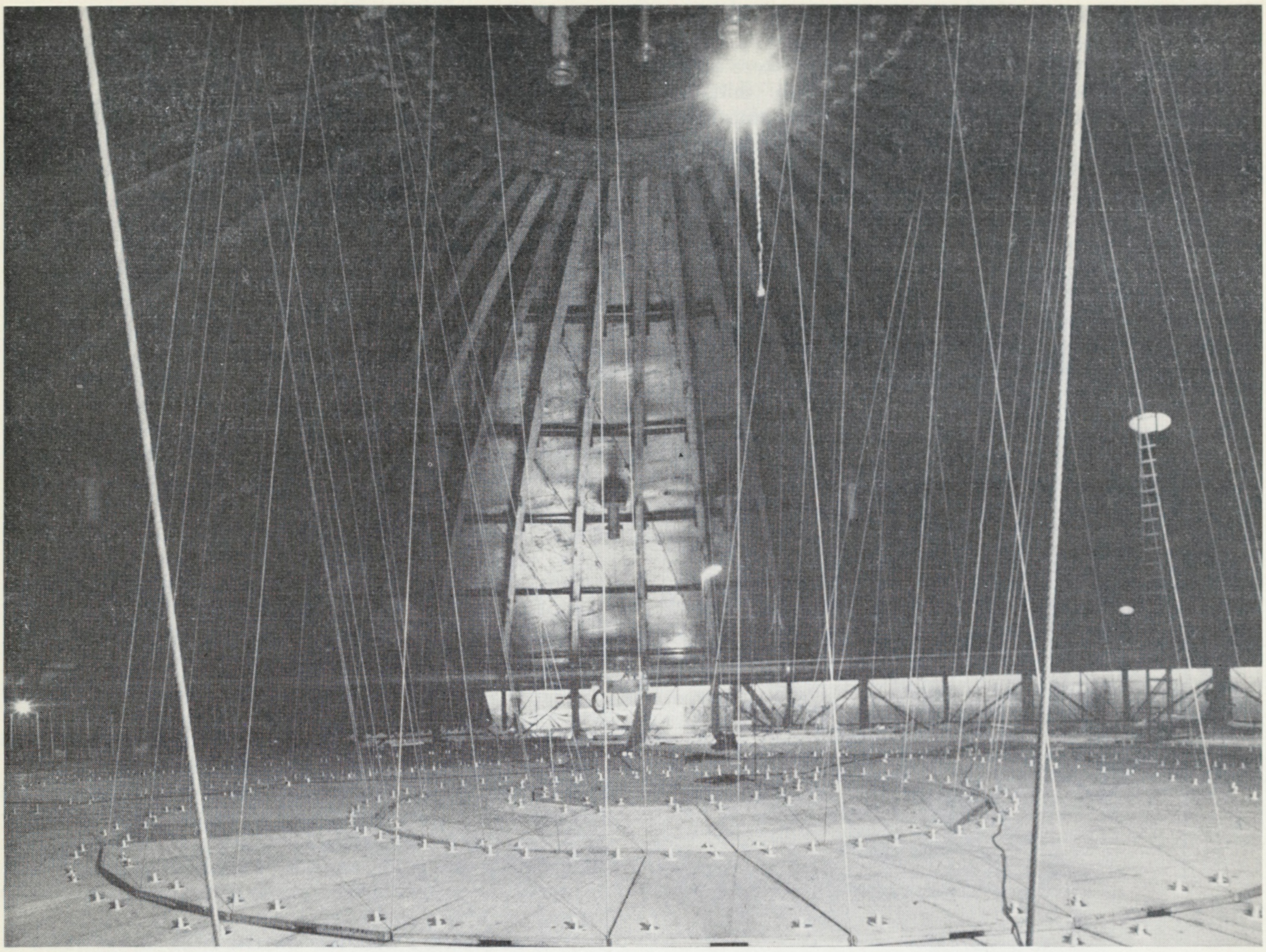

PLATE No. 2 PHOTOGRAPH SHOWING A TYPICAL SUSPENDED DECK ARRANGEMENT

meet 27J C_v at $-196°C$ as well as a minimum lateral expansion value (0.38 mm).

The British Standard requires 27J C_v at $-196°C$ in the longitudinal direction for the 9% nickel steel.

The API Standard requires the weld metal and heat affected zone of 9% nickel and $5\frac{1}{2}$% nickel to meet the same values as required for parent material. BS 5387 requires the weld metal only to meet the base plate requirements when welding 9% nickel steel.

4.3.3 **Design Stresses**

The maximum allowable design stress for the inner shell design in the British Specification is based upon factoring the minimum specified values of yield stress and ultimate tensile stress given in the appropriate Material Specification. Weld metal strength properties can control the allowable design stress. Maximum design stresses of 260 N/mm^2 for 9% nickel and stainless steel and 93 N/mm^2 for aluminium alloy are stated.

The American rules provide a table of maximum allowable design stresses for a list of permitted materials. Maximum stress values under test conditions are also included. These design and test stress values are based on the use of factors on parent plate and weld metal strength values which in practice result in lower design stresses than the British Specification. Table 3 compares the allowable maximum stresses in both specifications.

The outer tank shell design stresses are determined principally by the internal gas pressure plus insulation pressure, together with considerations of various other loadings, e.g. roof weight, wind loads, etc. Minimum shell thicknesses for various diameter ranges are included.

4.3.4 **Inspection**

The vertical welds of all single wall tanks and vertical welds of the inner tank in double wall containment require 100% radiographic inspection. The horizontal shell welds need not be fully radiographed but a recommendation that this be carried out is given in the British rules.

All butt welds in bottom annular plates are required to be radiographed over their full length.

Primary components not fully inspected by other means are required to be examined by crack detection methods. Butt welds in shell nozzles and mountings not amenable to radiography require full crack detection prior to the hydrostatic test.

5. GENERAL FABRICATION

The need for a designer to be fully aware of the shop and site fabrication methods employed in the construction of liquified gas storage containers is recognised in the rules governing such operations. The most careful attention to workmanship commencing in the production and acceptance of plate and other materials at the mill, shop fabrication operations, and the detailed methods and sequence employed in site construction, is essential if the design parameters upon which the integrity of the structure is based are to be achieved in practice.

An important aspect of tank construction is the overall and local departure from the design form. Such departures from the design shape, especially of the local type, almost invariably associated with welded joints, can result in significant stress concentrations.

In order to minimise these factors and to limit the degree of plastic strain during initial tank testing, both British and American rules limit the out of roundness and local departures from the design form. These limits are shown in Table 4.

In order to achieve the necessary tolerances and quality of fabrication, erection procedures are required which ensure accurate plating, allowances for contraction, correct vertical alignment and control of all temporary erection aids and attachments.

6. WELDING AND METALLURGICAL ASPECTS

All welding, including repair, tack and attachment welding, must be carried out in accordance with previously established procedures by qualified welders and operators. The welding practices employed range from manual/semi-automatic methods to fully mechanised techniques.

The control of manual welding operations relies heavily on good welder training and adequate welder supervision. The need to ensure adherance to welding parameters and techniques in manual welding is of paramount importance when the mechanical properties of weld deposits are highly dependent on the procedures adopted. This is particularly true in respect of the notch ductility of weld metal deposits for low temperature operation.

Satisfactory control of consumable manufacture and testing, followed by adequate storage and treatment of electrodes particularly on site, is fundamental to the achievement of satisfactory quality.

The use of semi-automatic and fully mechanised methods of welding offer advantages over manual methods in addition to the obvious benefits of increased productivity. The supervision of such operations is made easier provided careful operator training has been carried out and consumables have been correctly selected and handled during site operations.

It is anticipated that increased usage of mechanised welding systems will be employed in the future. Equipment for extended and continuous duty cycles in site operations must be of a robust and highly reliable nature, a point not always fully appreciated by equipment manufacturers. Satisfactory consumables (wire, flux and gas) must be available to meet the properties required by the design and further research effort is needed in this area.

Single walled tanks for storage of product down to approximately −50°C have traditionally been constructed from notch ductile ferritic steels welded with ferritic consumables and it is in this regime that significant differences exist between installations. The understanding of the prevention of fracture initiation has led to practices which provide minimum levels of notch ductility in base materials and welded joints which, when combined with inspection and a certain degree of overstressing at ambient temperatures inhibit fracture initiation from small flaws.

Such practices have been derived from research work carried out a number of years ago supplemented by additional information obtained from welded joints and newer consumables. While this approach has been shown to be reasonable, problems have been experienced in interpreting the results of small scale fracture mechanics tests such as crack opening displacement (COD) tests. Predictions of critical flaw sizes from such tests lead to limiting flaw sizes which are difficult to guarantee in practice and the validity of such predictions is currently the subject of much research work. The high levels of toughness demonstrated by Charpy V specimens does not necessarily result in high levels of COD and it is the authors' view that more work is urgently required if realistic toughness levels, satisfactory for adequate performance, are to be achieved at an economic cost.

TABLE 2

MATERIAL FOR PRIMARY COMPONENTS—API 620 APPENDIX R

	Design Metal Temperature		
	−51°C/−29°C	−29°C/−12°C	−12°C/+5°C
Plate	Transverse C_v values are required when design metal temperature limits are exceeded for specific listed material specifications and thicknesses.		
Pipe	ASTM A333	ASTM A106B(N)	C Steel Pipe
Structural Members	As above or Specific Notch Ductile Materials	As above or Specific Notch Ductile Materials	As above or Specific Notch Ductile Materials
Forgings	ASTM A350 LF2, etc.	ASTM A105 (Normalized)	General/Low Temp. Specifications
Bolts	ASTM A193 GR.B7 ASTM A320 GR.L7	ASTM A193 GR.B7 ASTM A320 GR.L7	Carbon Steel Bolts A193, A307, A320

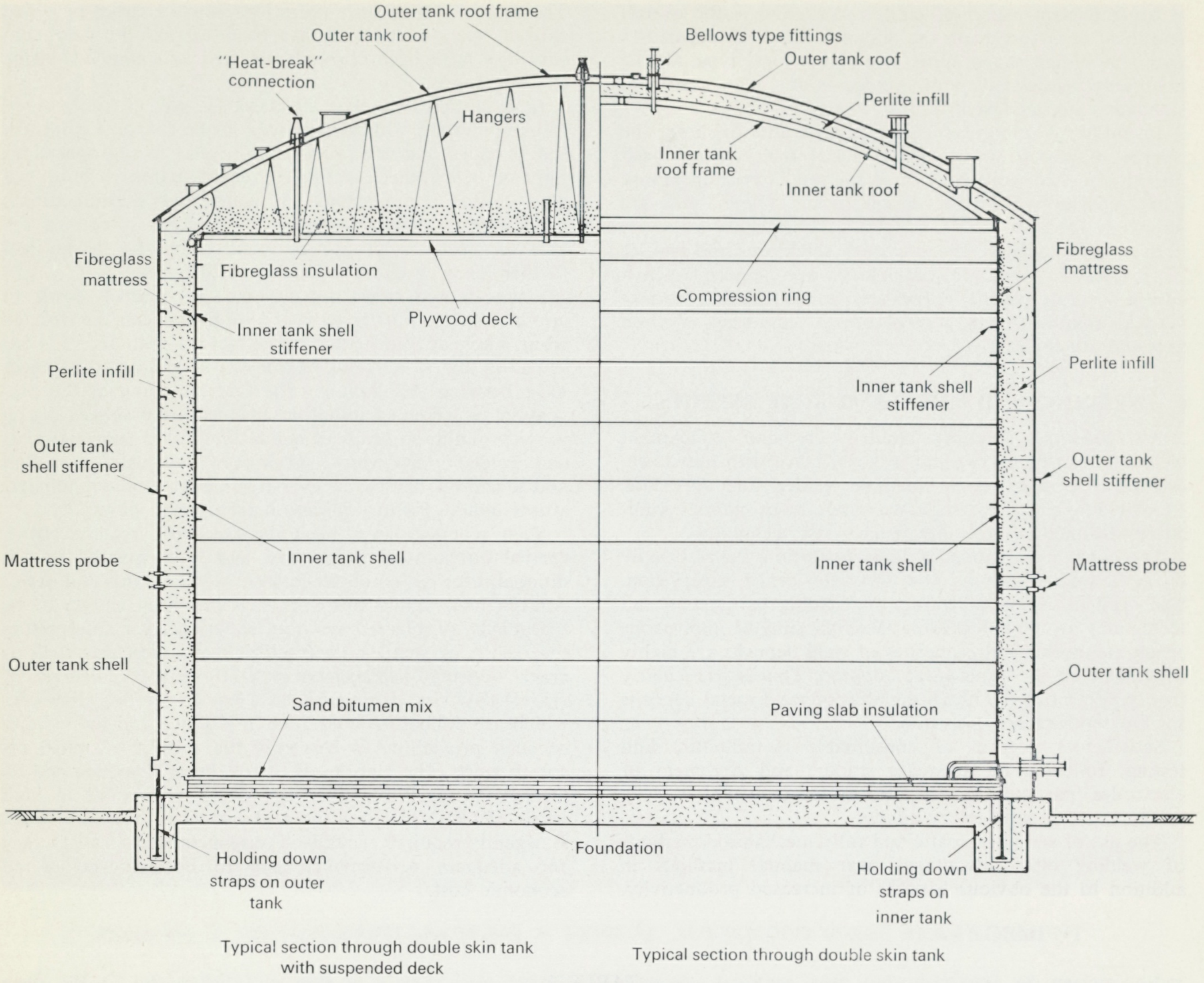

FIG. 3

SCHEMATIC ARRANGEMENT OF DOUBLE WALL TANK WITH INTERSPACE INSULATION

It should be appreciated that the provision of notch ductility is only a single aspect in the prevention of fracture initiation and the benefits to be derived from overstressing and careful inspection should also be taken into account. It is difficult to quantify the positive benefits derived from overstressing but it is believed that, for vessels of simple geometric form constructed to tolerances providing known departures from the design shape, an overstress provides significant benefits.

In the case of ferritic steels and weld metals it is considered beneficial that the weld metal overmatches the parent material.

Double wall tanks for the storage of liquid gas below about −100°C have their inner tanks constructed out of austenitic stainless steels, aluminium alloy or 9% nickel. The stainless and aluminium materials have extremely high resistance to fracture initiation whilst the 9% nickel steel welded with high Ni/Cr weld metals exhibits very good fracture behaviour at cryogenic temperatures. A major difference between "normal" ferritic constructions exists in the case of the 9% nickel material and possibly in other cases when the weld metal strength does not overmatch the base metal strength.

Fracture tests using such weld metal have demonstrated the high degree of ductility available and implies a tolerable flaw size of significant dimensions. Wide plate testing has confirmed the satisfactory behaviour of such joints with the currently used design stress levels (8).

7. TESTING

7.1 Ambient Mechanical Testing

Single wall tanks for the storage of liquefied gas down to −50°C are given a liquid test filling prior to operation at low temperature. The test consists of filling the tank to an agreed level and applying an overload air pressure in excess of the pressure for which the vapour space has been designed. The rules require the test water level to be equal to the design liquid level unless limited by other factors. The two principal limitations on the water test level relate to a maximum test stress, (80% and 85% of the minimum specified yield stress for the API and BSI rules respectively), and the need to ensure that the load on the foundations does not exceed the established allowable bearing load. Previously agreed limits of differential and overall foundation settlement must not be exceeded

during the course of the test. In practice, these additional constraints can result in water test levels below the liquid design level and provision is made for this in the British rules governing the notch ductility of those areas of the shell not subjected to a prior overload.

The inner and outer tanks of double walled cryogenic tanks are tested by filling the inner tank with water to an agreed level, inspecting for leakage, mechanical damage and foundation settlement, and pressurising the enclosed space above the water level to at least 1.25 times the pressure for which the vapour space is designed. Where a suspended inner deck is employed, this will also result in an air test of the outer tank.

In cases where an inner fixed roof is employed, special provisions for outer tank leak testing are required.

The water test level for the inner tank is again limited to maximum test stresses in the shell. The British rules limit the maximum stress to 1.25 times the allowable design stress for all materials while the American rules limit the maximum fill by the use of different factors on strength properties for different materials.

Maximum foundation loads and base insulation compressive loads are predetermined and must not be exceeded.

7.2 **Commissioning**

After all testing has been completed at ambient temperature and the outer tank has been shown to be leaktight, a detailed commissioning procedure converts the installation to its cold condition. Checks to ensure freedom from debris, obvious mechanical damage and water are important.

Careful drying out of the tank insulation, pipework and instrument lines followed by purging, usually with nitrogen, is necessary to prevent the creation of explosive atmospheres.

Where submerged discharge pumps and internal shutoff valves are employed, these should be carefully installed under controlled conditions, and monitored and actuated during the early stages of commissioning.

The tank is cooled at a controlled rate to reduce thermal overstressing until liquid accumulates in the base of the tank. Constant monitoring during this period is important to ensure satisfactory commissioning.

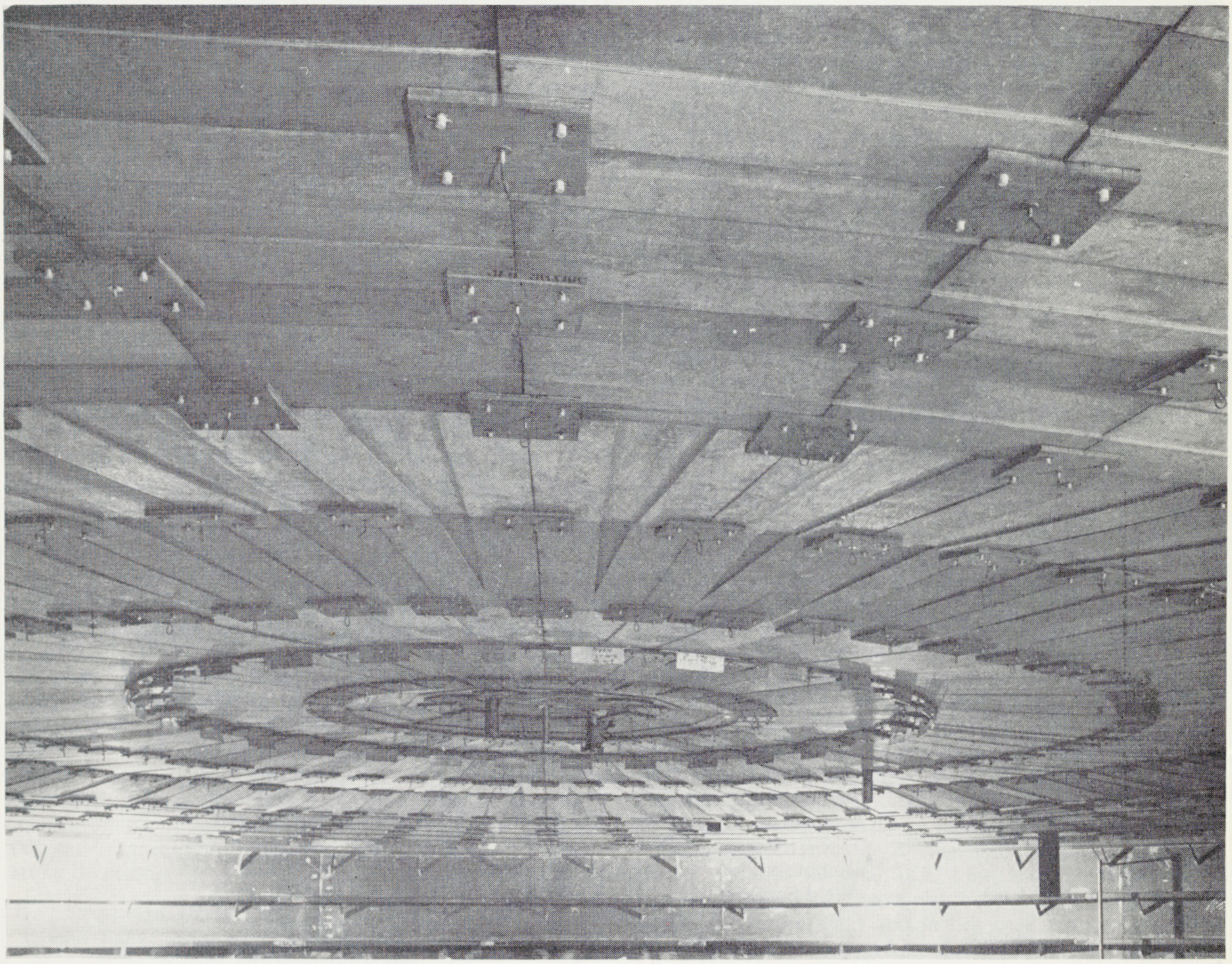

PLATE No. 3

PHOTOGRAPH OF THE UNDERSIDE OF A SUSPENDED DECK FROM WITHIN THE INNER TANK

TABLE 3

COMPARISON OF MAXIMUM ALLOWABLE STRESSES API 620 APPENDIX Q/BS 5378

Material	(Specified Minimum) U.T.S. N/mm²	Y.Pt.S. N/mm²		Max. Allowable Stress (N/mm²) Design B.S.	Design API	Test B.S.	Test API
9% Ni (N.N. & T.)	690	517		260[1]	219[2]	332	290
9% Ni (Q. & T.)	690	586		260[1]	219[2]	332	290
A1 Alloy B209–5083–0	276	124		—	92	—	112
A1 Alloy BS1477–NP8	278	139		93	—	118	—
Stainless Steel A240–Type 304	517	207	(0.2% PS)	—	155	—	186
BS1501–304S15	510	245	(1.0% PS)	163	—	208	—

(1) Weld metal minimum props.—based on procedure. U.T.S. = 689 N/mm² (Vertical weld); 551 N/mm² (Horizontal weld); Y.Pt.S. = 390 N/mm²

(2) Weld metal minimum props.—based on procedure. U.T.S. = 655 N/mm²; Y.Pt.S. = 362 N/mm²

TABLE 4

GENERAL LIMITS ON OUT OF ROUNDNESS AND LOCAL SHAPE DEPARTURE (CYLINDRICAL TANKS)

	British Requirements Diam. (d)		American Requirements Diam. (d)
Out of Roundness	⩾12.5 m >12.5 m⩽45 m >45 m	$d_{max} - d_{min} = 52$ mm $d_{max} - d_{min} = 76$ mm $d_{max} - d_{min} = 100$ mm	All diameters $d_{max} - d_{min} = \frac{d_{avge}}{100}$ or 304.8 mm (12″) whichever is the less
Verticality	⩾12.5 m >12.5 m⩽30 m >30 m⩽45 m >45 m	1 : 400 1 : 350 1 : 300 1 : 250	—
Local Departure (Gauge Length 2.5 m)	Remote from Weld Seams	At Welded Seams	
⩽12.5 mm plate thickness	16 mm	10 mm	The edges of the weld shall merge smoothly with the surface of the plate without a sharp angle.
>12.5 mm⩽25 mm	13 mm	8 mm	
>25 mm	10 mm	6 mm	

8. SPECIAL FEATURES

8.1 Pressure and Vacuum Relief Systems

The object of these systems is to limit the extremes of pressure within the tank to levels which will not impair the integrity of the storage installation.

The Standards are very similar in their requirements and all make reference to API Standard 2000 (9). Additional criteria are sometimes employed. The required valve capacities for venting other than under fire exposure conditions are based on the worst possible combination of the following.

Pressure

- Loss of refrigeration
- Control valve failure
- Liquid overfill
- Vapour displacement during filling
- Normal boil off
- Flash vapourisation during filling

Vacuum

- Withdrawal of liquid including gravity flow to another tank.
- Vapour withdrawal at maximum compressor suction rate.
- Rise in barometric pressure
- Reduction of vapour pressure due to the introduction of sub-cooled vapour.

The pressure rise has to be limited to 10% above the design pressure but the Standards vary in their recommendation on vacuum levels. API 620 gives 4.3 mbar provided the tank is designed to hold liquid. BS 4741 gives 8.5 mbar for similar conditions. API 620 makes no recommendation where the tank is designed for gas or vapour containment only, while BS 5387 gives 6 mbar for this condition.

Provision for extra venting may be required where the tank could be exposed to an external fire. A method of calculating the extra capacity required is given in API 2000. The method assumes that a fire will only heat the walls of a tank up to a height of 30 feet. There is evidence that this may not apply in the case of some low boiling liquids and BS 5387 requires the whole wetted height to be used. Some principal users have their own procedures for estimating fire venting requirements, which differ from API 2000.

Pilot operated valves are to be preferred for normal positive pressure venting as they are considered as "working valves" and should be tight just below set pressure and have good lift and blow down characteristics.

Weight loaded valves are often used for fire relief duties as they can be set to a higher opening pressure and, therefore, have an acceptable leakage at normal working pressure.

Vacuum relief valves are normally dead weight types as leakage near the set point is of little significance.

The Standards require that the valves shall be located so that they will never be sealed off by the contents or external sources such as snow and that cold vapour shall not impinge on the outer tank. It should also be emphasised that the design of safety valves in the system are of the "fail safe" type, which can usually be controlled by a variety of means.

8.2 Suspended Decks

Suspended roofs are now almost universally adopted for large LNG storage tanks. Whilst the cost benefits compared with inner fixed roofs can be significant, other features are of importance.

The provision of an internal roof which is not gas tight but merely designed to withstand the insulation and gas pressure differential loads in service and the loads imposed during construction, eliminates the possibility of overpressuring the inner tank. Roof vents are provided to accommodate gas flow between the inner tank and the roof space.

As shown in Plate No. 2, the deck is generally of flat configuration suspended from the outer roof by means of stainless steel wire ropes or rods. Made up of individual panels for easy erection, the roof supports insulation helping to control the boil off rate, and ensuring that the outer roof remains substantially constant at ambient temperature.

Thin metallic materials suitable for cryogenic temperatures, e.g. aluminium, stainless steel, etc., have been widely adopted for deck construction but other lightweight materials compatible with the product have been used. Plywood materials have been successfully tested and employed in a number of tanks with good experience. (See Plate No. 3). Relatively cheap low density glass fibre mattress insulation is used, as convection in this region is not a problem.

8.3 Insulation Systems

The Standards provide little detailed information on the design of insulation systems for low temperature storage tanks and it is left to a competent insulation engineer to provide a detailed specification for each application, taking into account the considerations given in the Standards. The British Standards are more detailed in this respect than the API Standards. The importance of the design cannot be over-emphasised as the failure of part of an insulation system in service could lead to failure of the storage tank.

The main purpose of the insulation is to limit the heat leak into the storage tank to an acceptable level under all operating conditions. The thermal design is relatively straightforward but the designer must also consider the effects of mechanical and thermal forces which generally increase with the size of the tank and he must recognize that inspection during service is limited, or in many cases, impracticable.

A competent and experienced insulation contractor should be employed for the installation using strict inspection and quality control procedures for both the materials and their application.

Considering first the base insulation, the conventional material choice is foamed glass which is of closed cell structure and non-burning. Care must be taken to exclude moisture from the system as repeated freeze/thaw cycling with entrapped water can cause progressive cell breakdown. The compressive strength of foamed glass is highly dependent on the interleaving material between successive layers as this distributes the load across the broken cell surfaces. This is demonstrated by the list of ambient temperature compression strength values quoted in Table 5.

Bitumen based interleaving materials are commonly used but the selected material should be demonstrated to behave satisfactorily under operating conditions. The area directly under the tank shell requires special consideration because of the additional line load. In some cases it may be necessary to provide a ring wall constructed from a higher strength material (e.g. low density concrete).

Loose fill materials have also been used for base insulation (e.g. foamed slag) and in this case the material must be dry and pre-compacted so that the deflection under load is minimised. The permeability of the material must be low so that natural convection does not increase the effective thermal conductivity.

Conventional materials for the shell and roof insulation for single walled tanks are foamed glass, rigid poly-

urethane or polyisocyanurate foams, the latter having superior fire resistance to P.U. Polyisocyanurates and P.U. can be foamed in-situ behind cleading, sprayed, or applied as slabstock. Whichever material or system is selected the most important factor is to provide an adequate permanent vapour seal on the outer surface to prevent the ingress of moisture due to the vapour pressure differential across the insulation. The vapour seal can be a continuous layer of a well proven mastic type material or overlapping sheets of galvanised, corrugated steel. In the latter case all the overlaps and rivetted joints must be vapour sealed. If the vapour seal is not permanent and complete, the ingress of moisture combined with freeze/thaw cycling which causes a breakdown of the cell structure, will lead ultimately to a deterioration in insulation performance. In the early stages this will increase the heat flow into the tank but in extreme cases the complete collapse of the insulation system could occur.

In double skinned tanks vapour sealing is not a problem because complete protection is provided by the outer tank. Expanded perlite is normally used for the sidewall insulation because of its low cost, ease of installation (it is site intumesced), low density, low thermal conductivity and low permeability which virtually eliminates natural convection. One disadvantage is that with repeated thermal cycling of the inner tank the material progressively compacts, building up an unacceptable external horizontal pressure on the inner tank.

This pressure is reduced by fitting a fibrous blanket (10) against the inner tank and this then acts as a spring which accommodates the thermal movement and prevents progressive perlite compaction. With this arrangement the horizontal pressure from the insulation is a function of the tank material and geometry, operating temperature range, perlite density, blanket material compression characteristics, blanket thickness and various friction coefficients. For any particular tank, the design can be optimised to minimise the total cost of insulation and inner tank

TABLE 5

AMBIENT TEMPERATURE ULTIMATE COMPRESSIVE STRENGTH TEST RESULTS—FOAMED GLASS (11)

Specimens listed in order of average failure load.

Capping Material	Test "A" kN/m²	Test "B" kN/m²	Test "C" kN/m²	Average kN/m²
Pluvex Damp-Proof No. 1 BS 743 Type A Hessian-based—Double Thickness	1680	1482	—	1581
Butyl Rubber—0.040″ Thick	1458	1563	—	1511
Pluvex Roofing Heavy 1.4 kg/m²—Single Thickness	1650	1328	—	1489
Butyl Rubber—0.030″ Thick	1298	1319	—	1309
Pluvex Damp-Proof—Single Thickness	1977	958	983	1306
Ruberoid Roofing 3-ply BS 747 IC—Single Thickness	873	1532	772	1060
Ruberoid Mineral Surface BS 747 3.6 kg/m²—Single Thickness ...	1241	574	—	908
Ruberoid Mineral Surface—Single Thickness	1044	672	—	858
Ruberoid Roofing 3-ply—Double Thickness	680	908	—	794
Thin Cardboard—Single Thickness	723	847	—	785
Thick Cardboard	574	958	—	766
Pluvex Roofing Heavy—Double Thickness	698	788	—	743
Butyl Rubber—0.060″ Thick	661	643	—	652
Thin Cardboard—Double Thickness	680	536	—	608
Absorbent Blotting Paper	556	624	—	590
Kieselguhr Powder and Aluminium Foil (0.05 mm)	154	395	—	275
Corrugated Paper—Double Thickness	198	117	—	158
Corrugated Paper—Single Thickness	136	99	—	117

$1 kN/m^2 = 0.145 lbf/in^2$

stiffening. Careful control of the properties of the insulation materials is required so that the calculated external load on the inner tank is not exceeded.

If the storage tank incorporates a suspended roof additional factors must be taken into consideration. The gas present in the insulation annulus is the vapour of the stored product and this will affect the thermal conductivity. Furthermore the contraction of the inner tank on cool down and during operation will result in settlement of the perlite, which requires special provisions as access in service is impractical.

This short summary highlights only the principal factors in insulation design. The detailed design and installation of insulation systems for low temperature bulk liquid storage should receive the same careful considerations as the tanks themselves. (11) (12).

8.4 Foundations

The provision of satisfactory foundations has been developed following many years of satisfactory experience with conventional oil storage units. Additional factors such as ground freezing and frost heave, thermal tank movement, anchorage against uplift, base insulation requirements and foundation settlement require careful consideration.

Rigid plinths supported on piles and ring wall type foundations have been used. Many infill materials of granular form and having suitable thermal and load bearing properties have also been employed. The test loading to prove foundations with particular significance attached to local differential settlement require subsoil and laboratory tests by a foundation specialist.

It is usual for the purchaser/user of the facility to take responsibility for providing satisfactory foundations. The ability to erect and fabricate large tanks to the tight tolerances now required is directly dependent on the quality of the foundations provided.

9. FUTURE TRENDS AND REQUIREMENTS

Because of operational flexibility and considerable technical difficulties, sea-borne transportation will continue as the preferred inter-continental transportation system rather than by sub-sea pipelines. Land based export and import terminals will continue to be a feature of the increasing usage of refrigerated liquids and as the size of shipment will increase so will the size of ships themselves and the size of the terminals. It follows, that there will be a demand to increase the unit size of storage tanks even though at the present time there has been a tendency to stabilise sizes whilst operational experience is accumulated.

Considerable pressure by Planning Authorities coupled with safety and environmental considerations (13) (14) will however provide the counter arguments to size escalation but in either event structures with increased levels of safety and of differing concept will be a feature of such installations. For example, double containment and/or double integrity will be more favoured and whilst there is no general tendency towards underground storage many authorities are moving towards concepts including earth ramps or berms around the storage unit. Along with these trends there is a need for a much clearer definition of the safety requirements and operational controls necessary. (15).

As these trends develop so also is the design process becoming more integrated with overall conceptual techniques. By way of example, suspended decks are desirable not only for their inherent advantage of cost savings but because the elemental parts of liquid pressure and gas pressure loadings are divorced, enabling a more analytical prediction of possible failure modes to be presented. By this means, liquid containment by the inner tank is separately considered from vapour pressure containment by the outer tank. Thus, in the unlikely event of overpressurisation, liquid product containment is secure.

There is as yet no general use of submersible pumps for double containment storage schemes for the whole range of refrigerated products, although submersible pumps for LNG are now relatively common, thus ensuring that there are no below liquid penetrations through either the inner or the outer container. As confidence in the use of pumps increases, it is likely that the trend to submersible pumps will also increase, particularly for the lower temperature products where the alternative design of bottom penetrations between inner and outer tanks is increasingly affected by differential movement.

A greater degree of emphasis on the design of relief systems for both process and emergency operational circumstances is predicted.

Both the overall conceptual changes and advances in detail solution are coupled with the trend to more sophisticated design techniques, and better quality materials. This is despite the fact that existing Codes of Practice have served the industry well. A number of well-publicised failures has drawn attention to the potential hazards in the storage and transportation of refrigerated liquids, and despite the good safety record over the last decades, this will inevitably lead to higher standards of fabrication and construction both by way of more detailed quality plans, quality control and inspection.

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